Replacement Copy AD-A267 583

REPORT DOCUMENTATION PAGE JUN 30 '93

Form Approved
OMB No 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE

3. REPORT TYPE AND DATES COVERED
ANNUAL 01 Jun 92 TO 31 May 93

4. TITLE AND SUBTITLE
ATMOSPHERIC IONIZATION BY SOLAR PARTICLES DETECTED BY NITRATE MEASUREMENTS IN ANTARCTIC SNOW

5. FUNDING NUMBERS
F49620-92-J-0235
61103D
3484
S4

6. AUTHOR(S)
Dr Gisela A. Dreschhoff

AD-A267 583

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Dept of Physics & Astronomy
University of Kansas
2291 Irving Hill Drive
Lawrence, KS 66045-2969

8. PERFORMING ORGANIZATION REPORT NUMBER
AEOSR-TR- 3 0559

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR/NL
110 Duncan Avenue, Suite B115
Bolling AFB DC 20332-0001

Dr Henry Radoski

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release;
distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Nitrates are observed in polar snow, firn and ice in variable amounts and concentrations. Hundred-year or longer time series of nitrate observations can be obtained from ice cores. It is important to identify possible and probable sources of nitrates and mechanisms by which surface deposition and incorporation into ice occurs. Several important sources of nitrate are solar protons and auroral electrons producing ionization in the D-region. Chemical reactions energized by this ionization produce nitrates. Transport mechanisms can move nitrates from the stratosphere into the troposphere where it becomes incorporated into precipitation. From the amounts of nitrates deposited in polar snow over long times it may be possible to determine atmospheric characteristics of importance to climate and global change studies. The specific goal of this study is to evaluate carefully and completely the atmospheric nitrates produced by solar flare protons and auroral electrons and to estimate the amounts deposited in snow.

14. SUBJECT TERMS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
(U)	(U)	(U)	(UL)

CRinc

THE UNIVERSITY OF KANSAS CENTER FOR RESEARCH, INC.
2291 Irving Hill Drive-Campus West Lawrence, Kansas 66045

AFOSR-F49620-J-0235DEF

ATMOSPHERIC IONIZATION BY SOLAR PARTICLES DETECTED BY NITRATE MEASUREMENT IN ANTARCTIC SNOW

G. Dreschhoff, T. P. Armstrong,
T. Cravens and F. Vitt

ANNUAL TECHNICAL REPORT

June 30, 1993

Contracting Officer: Capt. Marcia K. Vigil
Program Manager: Dr. Henry R. Radoski

Prepared For

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
BOLLING AFB, D.C., 20332-6448

Date: June 23, 1993

Memo to: Henry Radowski, AFOSR

From: Thomas P. Armstrong

Subject: Annual Report on AASERT Student, Francis Vitt

CC: Gisela Dreschoff
Thomas Cravens
Francis Vitt

This report will follow the suggested form for AFOSR Annual Technical Reports

Summary

Nitrates are observed in polar snow, firn and ice in variable amounts and concentrations. Hundred-year or longer time series of nitrate observations can be obtained from ice cores. It is important to identify possible and probable sources of nitrates and mechanisms by which surface deposition and incorporation into ice occurs. Several important sources of nitrate are solar protons and auroral electrons producing ionization in the D-region. Chemical reactions energized by this ionization produce nitrates. Transport mechanisms can move nitrates from the stratosphere into the troposphere where it becomes incorporated into precipitation. From the amounts of nitrates deposited in polar snow over long times it may be possible to determine atmospheric characteristics of importance to climate and global change studies. The specific goal of this study is to evaluate carefully and completely the atmospheric nitrates produced by solar flare protons and auroral electrons and to estimate the amounts deposited in snow.

Statement of Work and Work Accomplished

There are several phases to this problem. The initial phase, to refine and correct the solar proton ionization deposition code for the polar atmosphere is complete as documented in Attachment A. Both the COSPAR and the MSIS atmosphere models have been used. Attachment B describes the improvements to the computer code used by previous investigators. Attachment C describes the introduction of an improved description of the galactic cosmic ray contributions to atmospheric ionization. The development of a simplified model of the chemical reactions connecting ionization to nitrate production has begun. The next phase of work will include the acquisition and incorporation of a model of the auroral ionization from the NOAA Space Environment Laboratory. Also to be done is a one and two dimensional model of the transport of nitrate. Mr. Vitt is work this summer under the supervision of Dr. Charles Jackman of the Goddard Space Flight Center learning the skills necessary to run this model. He is also attending the summer lectures in Earth Science at GSFC to acquire further science background on atmospheric processes.

Publications

At this time there are only internal memos (attachments A,B, and C).
Some results may be ready for publication in the coming year and, of course, the complete results will be published in Mr. Vitt's PhD dissertation.

Participating Professionals

Mr. Francis Vitt is being supervised in his PhD studies jointly by Profs. Thomas Armstrong, Thomas Cravens, Ed. Zeller and Adjunct Prof. Gisela Dreschoff of the Department of Physics and Astronomy. Dr. Charles Jackman of the Goddard Space Flight Center will be appointed Adjunct to the Department of Physics and Astronomy faculty for the purpose of serving as the external member of Mr. Vitt's PhD committee.

Interactions

Mr. Vitt's is spending 6 weeks this summer at the Goddard Space Flight Center interacting with science staff and other students there.

Discoveries and Applications

The computer code being developed will, upon completion, be available to the government and public for the purpose of assisting in the evaluation of the global nitrate budget.

THE UNI RSITY OF KANSAS · LAWRE CE, KANSAS · 66045-2151

DEPARTMENT OF
PHYSICS & ASTRONOMY
913-864-4626
Fax 913-864-5262

Apendix A

August 6, 1992

MEMO

TO: Charles Jackman

FROM: F. Vitt, T. P. Armstrong, C. Laird, T. E. Cravens, G. Dreschhoff, E. Zeller

Referring to your e-mail of last year and our earlier discussions of the different results of our ionization calculations, we have examined the problem. We believe that we understand why the results differed.

1. Laird et al. underestimated the full upper hemisphere flux. Jackman method of integrating over incidence angle is better. Laird method now includes this.

2. Jackman approximation of spectrum is fairly coarse--overestimating and underestimating because of the 4 segment fit. Also, our contention is that power law is much more suitable for solar events at these energies.

The details are given below.

Regarding the calculation of ion pairs produced by energetic protons incident on the upper atmosphere using IMP8 data which has been done by Claude Laird and Charlie Jackman, daily average IMP8 data for day 293 of 1989 has been used. Integration of ion pairs per cubic cm over the altitude shows that Jackman's method tends to give more ionization than Laird's method, by about a factor of two. (See figure 1. Here the circles represent Laird's results, triangles represent Jackman's results.) To find the discrepancy between the two methods the following comparisons were done. Modifications were done to the Laird method to attempt to obtain results that match Jackman's.

Comparison of the two methods:

* Both assume that the number of ion pairs produced equals the energy deposited by the protons in the atmosphere divided by 35 eV.

* Laird uses the power law energy spectrum $\frac{dN}{dE} = A*E^{-\delta}$, where $\frac{dN}{dE}$ is the differential flux (no. of particles $*cm^{-2}*sr^{-1}*sec.^{-1}*MeV^{-1}$), A is the flux constant, δ is

the spectral exponent. A and δ are determined over nine energy ranges to fit the IMP8 data. This gives a piece wise continuous spectrum. (See figure 2.)

* Jackman uses an exponential energy spectrum given by $\frac{dN}{dE} = F*\exp(\frac{E}{E_0})$, where F and E_0 are determined over only four energy ranges to fit the IMP8 data. This gives relatively large discontinuities in the energy spectrum. (See figure 3.)

* Laird's energy spectrum ranges from 0.38 MeV to 289 MeV.

* Jackman's energy spectrum ranges from 0.29 MeV to 440 MeV.

* Laird's method:

Integration of the energy spectrum gives

$$N_i = \frac{24\text{ hrs}}{\text{day}} * \frac{3600\text{sec}}{\text{hr}} * \int_{E_i}^{E_{i+1}} \frac{dN}{dE} dE$$

= total no. of particles cm^{-2} sr^{-1} incident on the upper atmosphere for the day,

where E_i (i = 1,2,...,50) are logarithmically spaced energies ranging from 0.38 MeV to 289 MeV. This gives 49 mono-energetic fluxes with incident energy $E_i^0 = \sqrt{E_i * E_{i+1}}$.

These fluxes are followed vertically through the atmosphere, which is divided into 5 km slabs, as energy deposited in each slab is calculated, using a table look up method. Hence calculating energy deposited cm^{-2} s^{-1}. Then Laird multiplies by $\left(\frac{1}{35\times10^{-6}\text{MeV}} \frac{1}{5\times10^{5}\text{cm}} \frac{2\pi}{3} s\right)$ to get the units of no. of ion pairs cm^{-3}.

* Jackman's method:

Jackman assumes an isotropic distribution of pitch angle and azimuthal symmetry. Jackman calculates no. of ion pairs*cm^{-3}*$sec.^{-1}$ using the expression

$$q(z) = \rho(z) \int_E \int_\Omega \frac{dE}{dx} \frac{1}{W} \frac{dN}{dE} \, dE \, d\Omega$$

where $\frac{dN}{dE}$ is the differential flux (no.*cm^{-2}*sr^{-1}*sec^{-1}*MeV^{-1}), w = 35 eV per ion pair, $\rho(z)$ is the atmospheric density at the altitude z, $\frac{dE}{dx}$ is the energy deposited per gm.

Let $E_D = dE$ be the energy deposited by a particle of energy E with a pitch angle α in the segment z_D, z_D = width of the atmospheric layer in gm*cm^{-2} centered on the altitude z.

If $\frac{dN}{dE}(E_0,\alpha,z)$ = flux of particles with incident energy E_0 at a pitch angle α at the altitude z is known, then $q_{i,j}(\Delta,z)$ = ionization rate by a flux of particles in the energy interval $E_0 - \frac{\Delta E}{2}$ to $E_0 + \frac{\Delta E}{2}$, and in the pitch angle interval $\alpha - \frac{\Delta\alpha}{2}$ to $\alpha + \frac{\Delta\alpha}{2}$ over the atmospheric distance z_D centered on the altitude z can be calculated with the expression

$$q_{i,j}(\Delta,z) = 2\pi \int_{E_0-\frac{\Delta E_0}{2}}^{E_0+\frac{\Delta E_0}{2}} \int_{\alpha-\frac{\Delta\alpha}{2}}^{\alpha+\frac{\Delta\alpha}{2}} E_D \frac{\frac{dN}{dE}(E_0,\alpha,z)}{w\, z_D \sec\alpha} \sin\alpha \, d\alpha \, dE$$

Assuming E_D and $\frac{dN}{dE}(E_0,\alpha,z)$ change slowly enough within the pitch angle interval we can write

$$q_{i,j}(\Delta,z) = \frac{2\pi}{w\, z_D} \int_{E_0-\frac{\Delta E}{2}}^{E_0+\frac{\Delta E}{2}} \frac{dN}{dE}(E_0,\alpha,z)\, E_D \, dE \int_{\alpha-\frac{\alpha}{2}}^{\alpha+\frac{\alpha}{2}} \cos\alpha \sin\alpha \, d\alpha$$

$$= \frac{\pi}{w\, z_D} [\sin^2(\alpha+\frac{\Delta\alpha}{2}) - \sin^2(\alpha-\frac{\Delta\alpha}{2})] \int_{E_0-\frac{\Delta E}{2}}^{E_0+\frac{\Delta E}{2}} \frac{dN}{dE}(E_0,\alpha,z)\, E_D \, dE$$

To calculate the energy deposited Jackman uses the expression for the range as $R(E) = A*E^B$, thus

$$E_D = E - (-\frac{z_D * \sec\alpha}{A} + E^B)^{\frac{1}{B}}$$

Hence, the ionization rate at the altitude z is

$$q(z) = \rho(z) \sum_{i,j} q_{i,j}(\Delta,z)$$
$$= \text{no. of ion pairs cm}^{-3}\ \text{sec}^{-1}.$$

Modifications to the Laird method:

Assume an isotropic distribution of pitch angle between 0 and $\frac{\pi}{2}$ and azimuthal symmetry. Let α_k be 50 evenly spaced angles between 0 and $\frac{\pi}{2}$, the fluxes with pitch angle between α_k and α_{k+1} have the pitch angle α_k^0 such that $\cos \alpha_k^0 = \sqrt{\cos \alpha_k * \cos \alpha_{k+1}}$.

Let $q_{i,j,k}$ = the no. of ion pairs*cm^{-3} produced by the flux with incident energy E_i^0 in the j^{th} slab centered at altitude z_j with pitch angle α_k^0. So,

$$q_{i,j,k} = \frac{1}{35\text{x}10^{-6}\text{MeV}} \int_{\Delta\Omega} N_i \frac{E_{D,i,j,k}}{\Delta X_{j,k}} d\Omega$$

where $E_{D,i,j,k}$ is the energy deposited by a proton with incident energy E_i^0, pitch angle α_k^0, in the j^{th} slab. $\Delta X_{j,k}$ is the effective thickness of the j^{th} slab, i.e. $\Delta X_{j,k} = \Delta Z_j * \sec\alpha_k^0$, ΔZ_j is the thickness of the slab (5km). N_i (for i = 1,2,...49) is the mono-energetic flux with incident energy E_i^0. And $\Delta\Omega$ is the solid angle between α_k and α_{k+1} as Φ varies from 0 to 2π.

Assuming N_i, $E_{D,i,j,k}$, and $\Delta X_{j,k}$ do not change significantly as pitch angle varies between α_k and α_{k+1}, we can write

$$q_{i,j,k} = \frac{1}{35\text{x}10^{-6}\text{MeV}} N_i \frac{E_{D,i,j,k}}{\Delta Z_j} (\cos \alpha_k^0) \Delta\Omega_k$$

where

$$\Delta\Omega_k = \int_0^{2\pi} d\Phi \int_{\alpha_k}^{\alpha_{k+1}} \sin \vartheta d\vartheta = 2\pi(\cos\alpha_{k+1} - \cos \alpha_k)$$

Summing over incident energies and pitch angles we can calculate the total no. of ion pairs cm^{-3} produced the j^{th} slab, Q_j, i.e.

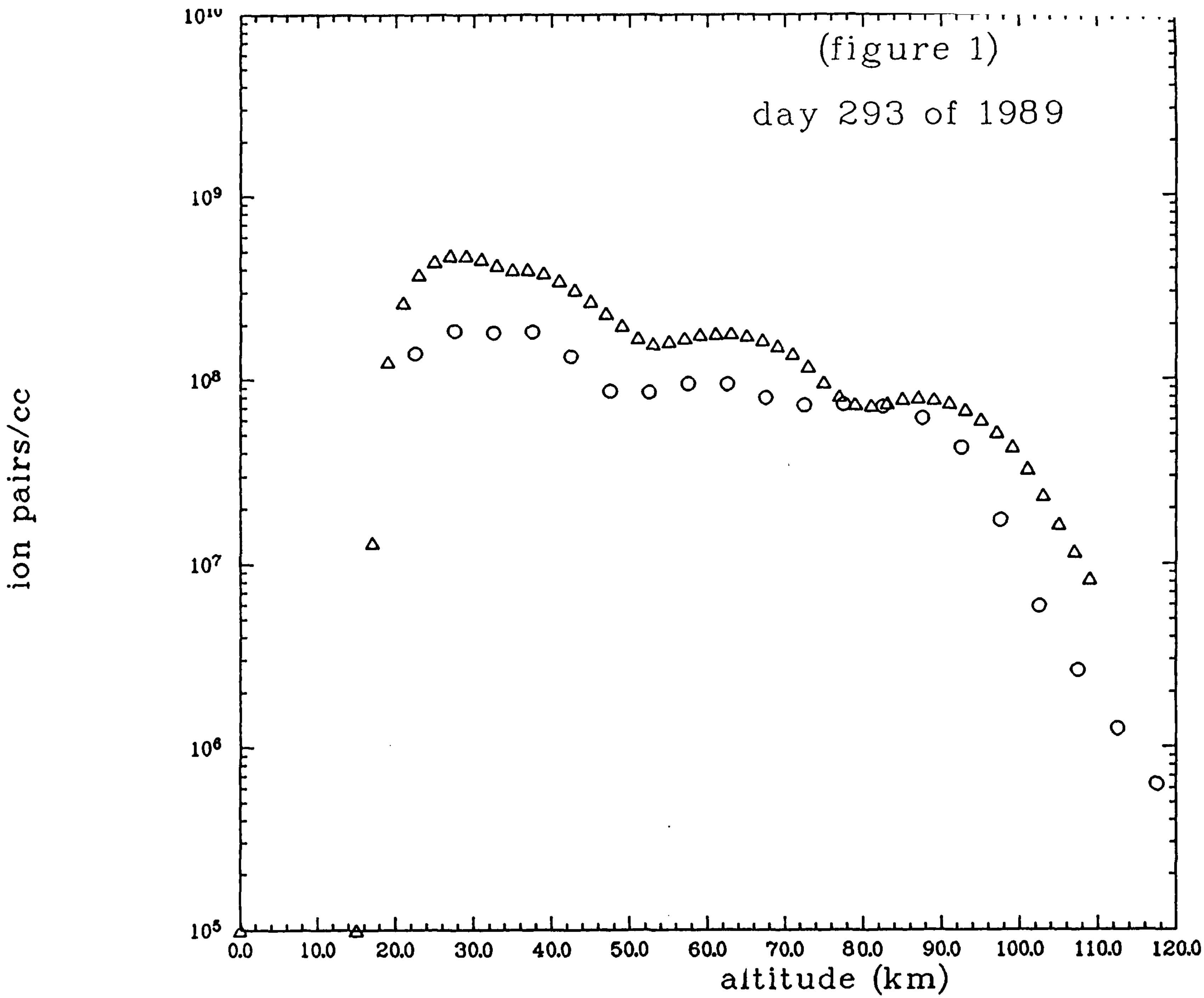
$$Q_j = \sum_{i,k} q_{i,j,k}$$

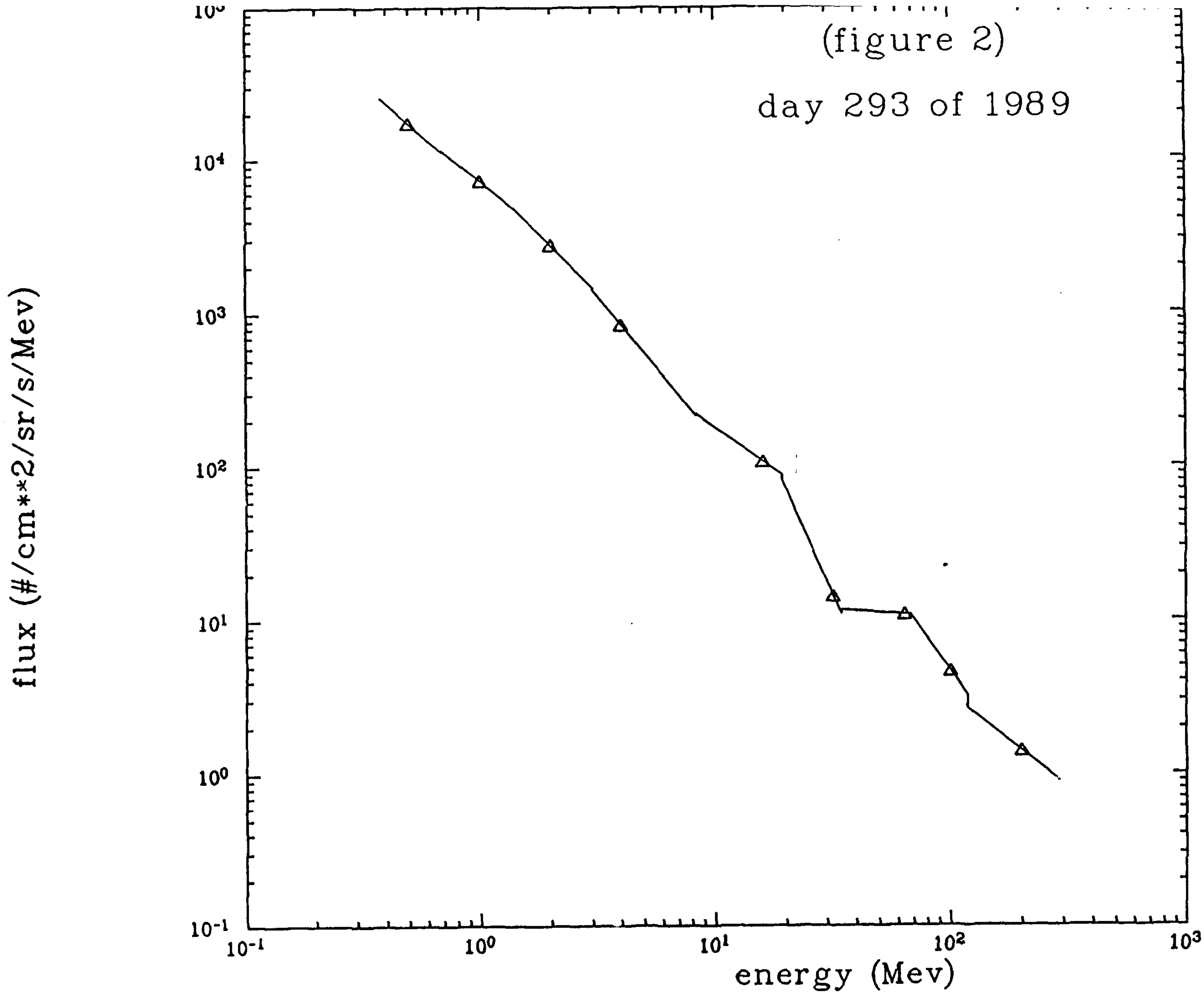
Integrating the ion pairs cm^{-3} produced over altitude, where Laird's power law spectrum was used to calculate the 49 mono-energetic fluxes, gives a higher ionization for the modified Laird method by about a factor of 1.5 compared to the results of the unmodified Laird method for day 293 of 1989. (See figure 4. Here the circles represent the results of the unmodified Laird method, the triangles represent Jackman's results, while the squares represent the results of the modified Laird method.)

Using Jackman's exponential spectrum to calculate the 49 mono-energetic fluxes for the modified Laird method gives a result which very closely resembles Jackman's. (See figure 5. The circles, triangles, and squares represent the same as in figure 4.)

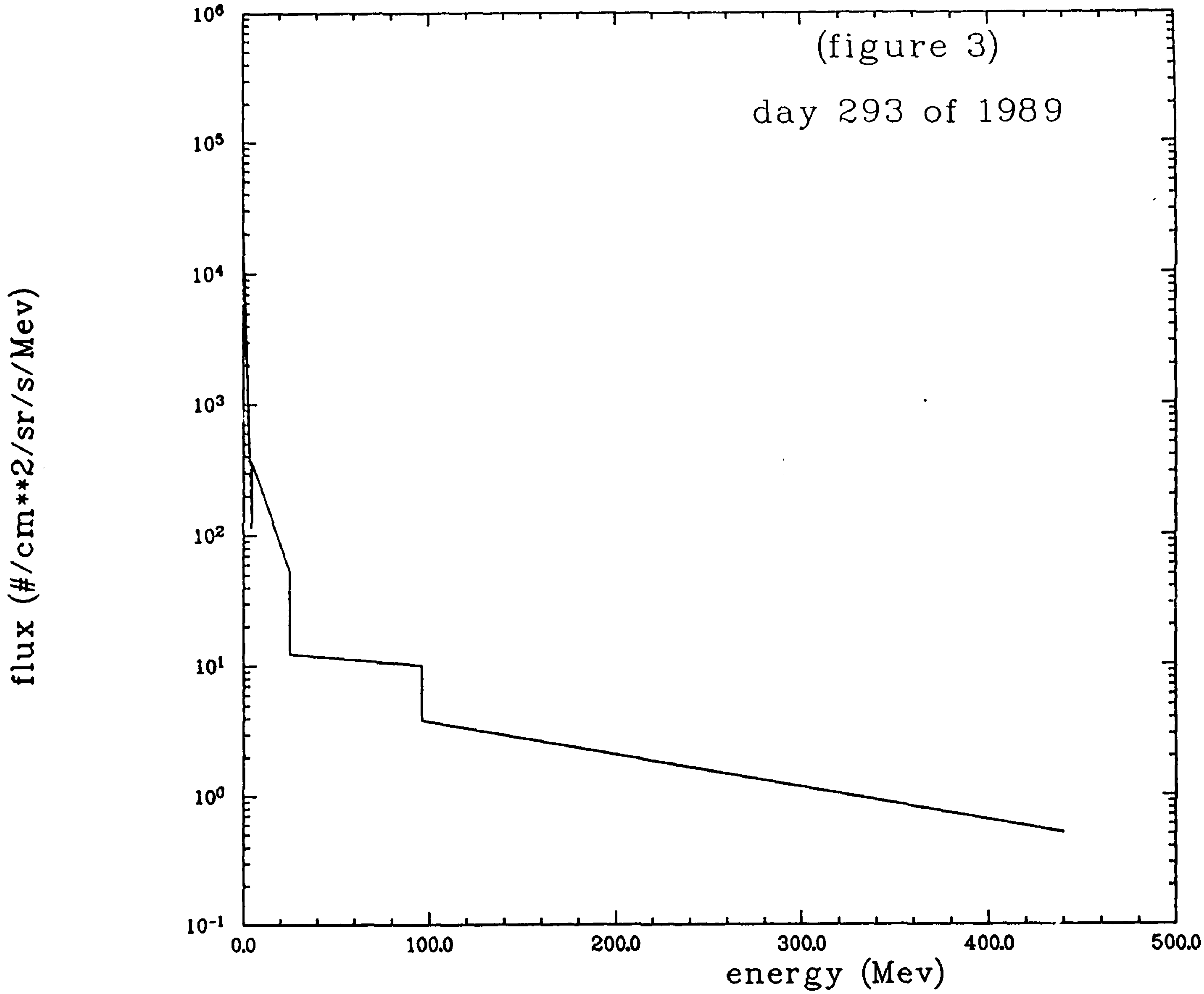
/thw

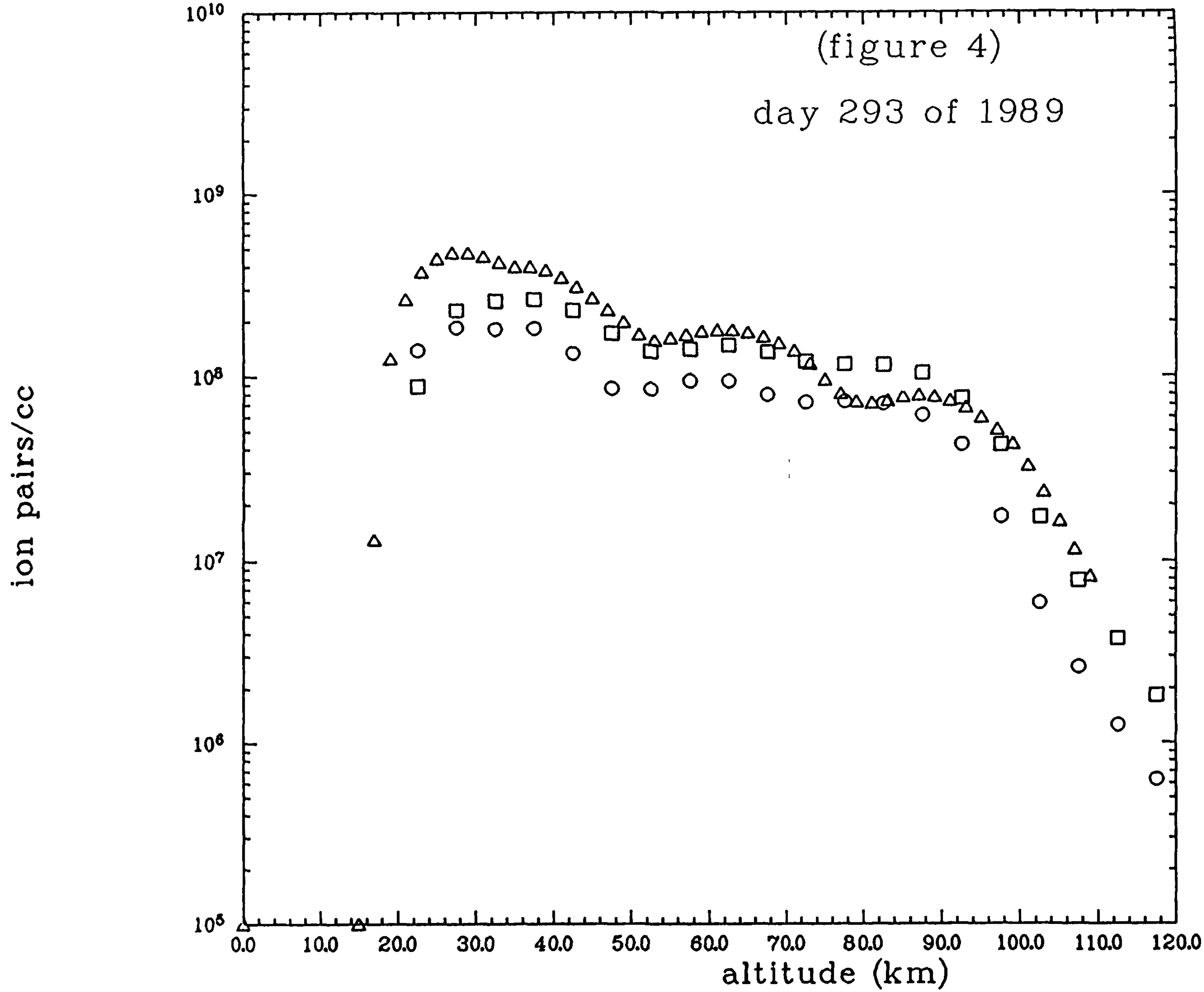
cc: File

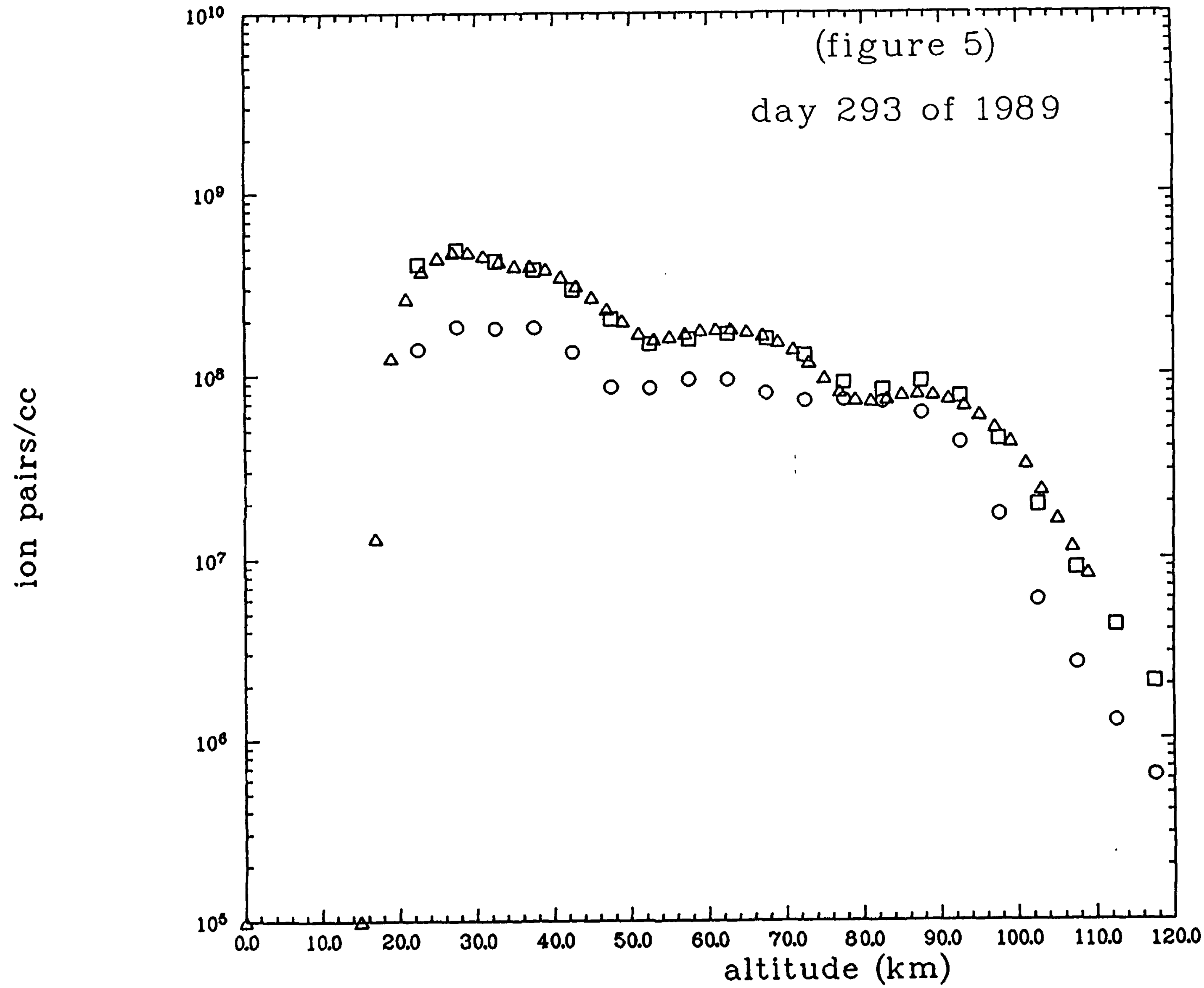

(figure 1)
day 293 of 1989
ion pairs/cc
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0
120.0
altitude (km)



(figure 2)
day 293 of 1989
flux (#/cm**2/sr/s/Mev)
energy (Mev)
10^-1
10^0
10^1
10^2
10^3
10^4
10^5


(figure 3)
day 293 of 1989
flux (#/cm**2/sr/s/Mev)
energy (Mev)
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.0
100.0
200.0
300.0
400.0
500.0


(figure 4)
day 293 of 1989
ion pairs/cc
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0
120.0
altitude (km)


(figure 5)
day 293 of 1989
ion pairs/cc
altitude (km)
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0
120.0

#32 7-FEB-1991 16:19:19.35 IMP8

From: 6187::JACKMAN
To: KUPHSX::ARMSTRONG,KUPHSX::LAIRD
CC:
Subj: Ion Pair Production for 1989

February 7, 1991

Tom and Claude,

I thought that maybe if we concentrated on just one day, that we might be able to track down our differences. The day I have chosen to give you more detailed information is the day that I compute maximum ion pair production in the year 1989.
Here is the raw data that you sent to me for day 293 of year 1989 for channels P1 - P11:

```
1                        IMP8 1989 DAILY AVG. PROTON FLUXES
0YR=1989 DAY=  2   0  0  0 XSE= 34.65 YSE= -5.36 ZSE= 11.92
 YEAR DAY HH MM SS   P1AV       P2AV       P3AV       P4AV       P5AV

,1989 293  0  0  0  0.806E+04  0.755E+04  0.855E+04  0.559E+04  0.350E+04
1                        IMP8 1989 DAILY AVG. PROTON FLUXES
0YR=1989 DAY=  2   0  0  0 XSE= 34.65 YSE= -5.36 ZSE= 11.92
 YEAR DAY HH MM SS   P7AV       P8AV       P9AV       P10AV      P11AV
,1989 293  0  0  0   273.       87.3       165.       52.2       85.5
```

I derived flux values (# cm-2 s-1 sr-1 MeV-1) from this data. I combined the P1 and P2 channels and also the P3 and P4 channels. The energy intervals, middle energy chosen, channels taken, and fluxes computed are given below for day 293.

Energy intervals (MeV)	Middle energy chosen (MeV)	Channels taken	Flux computed (# cm-2 s-1 sr-1 MeV-1)
0.29-0.96	0.5	P1 & P2	15,429.
0.96-4.6	2.0	P3 & P4	2572.6
4.6-15.	9.8	P5	222.87
15.-25.	20.	P7	85.313
25.-48.	36.5	P8	11.861
48.-96.	72.	P9	10.742
96.-145.	120.5	P10	3.329
190.-440.	315.	P11	1.069

Here is some information on fits to the data for day 293.
The relationship used is Flux = F * exp(-E/E0) where Flux is in units of # cm-2 s-1 sr-1 MeV-1.
The values of F and E0 and the energy bands over which I have applied them are given below:

F	E0 (MeV)	Energy band applied (MeV)
0.280E+05	0.837E+00	0.29-4.6
0.561E+03	0.106E+02	4.6-25
0.131E+02	0.358E+03	25-96
0.673E+01	0.171E+03	96-440

Next I give you output from my energy degradation program. I give height(km), ion pair production per cm+3 per sec, and ion pair production per cm+3 per hour.

DAY= 293.00

HEIGHT(KM)	Q(ION PAIRS/(CM+3 SEC))	Q(ION PAIRS/(CM+3 HOUR))
1.090E+02	9.613E+01	3.461E+05
1.070E+02	1.342E+02	4.830E+05
1.050E+02	1.907E+02	6.864E+05
1.030E+02	2.719E+02	9.788E+05
1.010E+02	3.787E+02	1.363E+06
9.900E+01	4.966E+02	1.788E+06
9.700E+01	5.928E+02	2.134E+06
9.500E+01	6.920E+02	2.491E+06
9.300E+01	7.831E+02	2.819E+06
9.100E+01	8.524E+02	3.069E+06
8.900E+01	8.968E+02	3.228E+06
8.700E+01	9.152E+02	3.295E+06
8.500E+01	8.974E+02	3.231E+06
8.300E+01	8.520E+02	3.067E+06
8.100E+01	8.312E+02	2.992E+06
7.900E+01	8.477E+02	3.052E+06
7.700E+01	9.332E+02	3.360E+06
7.500E+01	1.112E+03	4.004E+06
7.300E+01	1.356E+03	4.881E+06
7.100E+01	1.606E+03	5.781E+06
6.900E+01	1.766E+03	6.359E+06
6.700E+01	1.907E+03	6.865E+06
6.500E+01	2.018E+03	7.266E+06
6.300E+01	2.076E+03	7.473E+06
6.100E+01	2.070E+03	7.453E+06
5.900E+01	2.047E+03	7.370E+06
5.700E+01	1.960E+03	7.055E+06
5.500E+01	1.877E+03	6.758E+06
5.300E+01	1.820E+03	6.554E+06
5.100E+01	1.966E+03	7.078E+06
4.900E+01	2.303E+03	8.290E+06
4.700E+01	2.684E+03	9.662E+06
4.500E+01	3.122E+03	1.124E+07
4.300E+01	3.604E+03	1.298E+07
4.100E+01	4.038E+03	1.454E+07
3.900E+01	4.451E+03	1.602E+07
3.700E+01	4.639E+03	1.670E+07
3.500E+01	4.637E+03	1.669E+07
3.300E+01	4.893E+03	1.762E+07
3.100E+01	5.284E+03	1.902E+07
2.900E+01	5.516E+03	1.986E+07
2.700E+01	5.525E+03	1.989E+07
2.500E+01	5.138E+03	1.850E+07
2.300E+01	4.365E+03	1.571E+07
2.100E+01	3.084E+03	1.110E+07
1.900E+01	1.461E+03	5.260E+06
1.700E+01	1.519E+02	5.469E+05
1.500E+01	0.000E+00	0.000E+00

1.300E+01	0.000E+00	0.000E+00
1.100E+01	0.000E+00	0.000E+00
9.000E+00	0.000E+00	0.000E+00
7.000E+00	0.000E+00	0.000E+00
5.000E+00	0.000E+00	0.000E+00
3.000E+00	0.000E+00	0.000E+00
1.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00

Here is the standard atmosphere that I use:

US. STND. ATMOS. 1976

45 AVE

Alt(km)	Temp.	Density(kg/m+3)
110.	240.0	9.708E-08
108.	223.3	1.381E-07
106.	212.9	1.954E-07
104.	205.3	2.769E-07
102.	199.5	3.935E-07
100.	195.1	5.604E-07
98.	191.7	8.071E-07
96.	189.3	1.162E-06
94.	187.7	1.670E-06
92.	187.0	2.393E-06
90.	186.9	3.416E-06
88.	186.9	4.875E-06
86.	186.9	6.958E-06
84.	190.8	9.694E-06
82.	194.7	1.342E-05
80.	198.6	1.846E-05
78.	202.5	2.524E-05
76.	206.4	3.431E-05
74.	210.4	4.639E-05
72.	214.3	6.237E-05
70.	219.6	8.283E-05
68.	225.1	1.092E-04
66.	230.5	1.430E-04
64.	236.0	1.861E-04
62.	241.5	2.407E-04
60.	247.0	3.097E-04
58.	252.5	3.963E-04
56.	258.0	5.045E-04
54.	263.5	6.390E-04
52.	269.0	8.056E-04
50.	270.7	1.027E-03
48.	270.7	1.317E-03
46.	266.9	1.714E-03
44.	261.4	2.259E-03
42.	255.9	2.995E-03
40.	250.4	3.996E-03
38.	244.8	5.367E-03
36.	239.3	7.258E-03
34.	233.7	9.887E-03
32.	228.5	1.356E-02
30.	226.5	1.841E-02
28.	224.5	2.508E-02

26.	222.5	3.426E-02
24.	220.6	4.694E-02
22.	218.6	6.645E-02
20.	216.7	8.891E-02
18.	216.7	1.217E-01
16.	216.7	1.665E-01
14.	216.7	2.279E-01
12.	216.7	3.119E-01
10.	223.3	4.135E-01
8.	236.2	5.258E-01
6.	249.2	6.601E-01
4.	262.2	8.194E-01
2.	275.2	1.007E+00
0.0	288.2	1.225E+00

Next are a couple of simple spectra with resultant ion pair production. First, an exponential fit: Flux= 100 exp(-E/30) where E is in MeV and Flux is in # cm-2 s-1 sr-1 MeV-1.

Results from my energy degradation program using this spectra:

HEIGHT(KM)	Q(ION PAIRS/(CM+3 SEC))	Q(ION PAIRS/(CM+3 HOUR))
1.090E+02	2.728E+00	9.822E+03
1.070E+02	3.866E+00	1.392E+04
1.050E+02	5.479E+00	1.972E+04
1.030E+02	7.764E+00	2.795E+04
1.010E+02	1.101E+01	3.964E+04
9.900E+01	1.554E+01	5.596E+04
9.700E+01	2.171E+01	7.814E+04
9.500E+01	3.019E+01	1.087E+05
9.300E+01	4.177E+01	1.504E+05
9.100E+01	5.739E+01	2.066E+05
8.900E+01	7.836E+01	2.821E+05
8.700E+01	1.068E+02	3.845E+05
8.500E+01	1.432E+02	5.156E+05
8.300E+01	1.881E+02	6.772E+05
8.100E+01	2.443E+02	8.796E+05
7.900E+01	3.151E+02	1.134E+06
7.700E+01	3.998E+02	1.439E+06
7.500E+01	5.045E+02	1.816E+06
7.300E+01	6.268E+02	2.257E+06
7.100E+01	7.693E+02	2.769E+06
6.900E+01	9.254E+02	3.331E+06
6.700E+01	1.103E+03	3.972E+06
6.500E+01	1.286E+03	4.630E+06
6.300E+01	1.482E+03	5.335E+06
6.100E+01	1.686E+03	6.068E+06
5.900E+01	1.871E+03	6.736E+06
5.700E+01	2.048E+03	7.372E+06
5.500E+01	2.203E+03	7.929E+06
5.300E+01	2.330E+03	8.389E+06
5.100E+01	2.396E+03	8.626E+06
4.900E+01	2.475E+03	8.909E+06
4.700E+01	2.486E+03	8.950E+06
4.500E+01	2.462E+03	8.863E+06
4.300E+01	2.380E+03	8.566E+06
4.100E+01	2.185E+03	7.866E+06

3.900E+01	1.911E+03	6.878E+06
3.700E+01	1.566E+03	5.636E+06
3.500E+01	1.210E+03	4.357E+06
3.300E+01	8.300E+02	2.988E+06
3.100E+01	5.134E+02	1.848E+06
2.900E+01	2.783E+02	1.002E+06
2.700E+01	1.232E+02	4.436E+05
2.500E+01	4.878E+01	1.756E+05
2.300E+01	1.371E+01	4.936E+04
2.100E+01	3.189E+00	1.148E+04
1.900E+01	3.363E-01	1.211E+03
1.700E+01	0.000E+00	0.000E+00
1.500E+01	0.000E+00	0.000E+00
1.300E+01	0.000E+00	0.000E+00
1.100E+01	0.000E+00	0.000E+00
9.000E+00	0.000E+00	0.000E+00
7.000E+00	0.000E+00	0.000E+00
5.000E+00	0.000E+00	0.000E+00
3.000E+00	0.000E+00	0.000E+00
1.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00

Second, a power law fit: Flux= 100,000. * (E/1)**(-2) where E is in MeV and Flux is in # cm-2 s-1 sr-1 MeV-1.

Results from my energy degradation program using this spectra:

HEIGHT(KM)	Q(ION PAIRS/(CM+3 SEC))	Q(ION PAIRS/(CM+3 HOUR))
1.090E+02	2.129E+03	7.665E+06
1.070E+02	3.015E+03	1.085E+07
1.050E+02	4.327E+03	1.558E+07
1.030E+02	6.124E+03	2.205E+07
1.010E+02	8.388E+03	3.020E+07
9.900E+01	1.022E+04	3.679E+07
9.700E+01	1.009E+04	3.634E+07
9.500E+01	9.833E+03	3.540E+07
9.300E+01	9.608E+03	3.459E+07
9.100E+01	9.426E+03	3.393E+07
8.900E+01	9.309E+03	3.351E+07
8.700E+01	9.241E+03	3.327E+07
8.500E+01	9.083E+03	3.270E+07
8.300E+01	8.857E+03	3.188E+07
8.100E+01	8.656E+03	3.116E+07
7.900E+01	8.466E+03	3.048E+07
7.700E+01	8.304E+03	2.989E+07
7.500E+01	8.159E+03	2.937E+07
7.300E+01	7.978E+03	2.872E+07
7.100E+01	7.835E+03	2.821E+07
6.900E+01	7.629E+03	2.746E+07
6.700E+01	7.469E+03	2.689E+07
6.500E+01	7.287E+03	2.623E+07
6.300E+01	7.084E+03	2.550E+07
6.100E+01	6.966E+03	2.508E+07

5.900E+01	6.799E+03	2.448E+07
5.700E+01	6.633E+03	2.388E+07
5.500E+01	6.485E+03	2.335E+07
5.300E+01	6.382E+03	2.298E+07
5.100E+01	6.234E+03	2.244E+07
4.900E+01	6.235E+03	2.245E+07
4.700E+01	6.227E+03	2.242E+07
4.500E+01	6.305E+03	2.270E+07
4.300E+01	6.438E+03	2.318E+07
4.100E+01	6.494E+03	2.338E+07
3.900E+01	6.560E+03	2.362E+07
3.700E+01	6.602E+03	2.377E+07
3.500E+01	6.611E+03	2.380E+07
3.300E+01	6.515E+03	2.345E+07
3.100E+01	6.333E+03	2.280E+07
2.900E+01	5.945E+03	2.140E+07
2.700E+01	5.371E+03	1.934E+07
2.500E+01	4.628E+03	1.666E+07
2.300E+01	3.530E+03	1.271E+07
2.100E+01	2.198E+03	7.912E+06
1.900E+01	5.981E+02	2.153E+06
1.700E+01	0.000E+00	0.000E+00
1.500E+01	0.000E+00	0.000E+00
1.300E+01	0.000E+00	0.000E+00
1.100E+01	0.000E+00	0.000E+00
9.000E+00	0.000E+00	0.000E+00
7.000E+00	0.000E+00	0.000E+00
5.000E+00	0.000E+00	0.000E+00
3.000E+00	0.000E+00	0.000E+00
1.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00

I am faxing a plot of the proton flux versus energy for day 293. The data are represented as +'s and my fit as a solid line. The discontinuities arise when the e-folding and amplitude values change for the different energy bands.

I doubt if we will ever compute exactly the same ion pair production, but it would be nice to be within a factor of two of eachother.

Thanks again for spending time on this.

Sincerely,
Charley Jackman

SPAN address - PACF::JACKMAN
Phone (301)286-8399
FAX (301)286-263

Oct. 3, 1992

TO: C. Jackman, T. P. Armstrong, C. Laird, T. E. Cravens, G. Dreschhoff, E. Zeller

FROM: Francis Vitt

After having resolved the differences between C. Jackman's method and C. Laird's and T. P. Armstrong's method of calculating ionization of the atmosphere, to bring us up to date on the computational work done on the calculations, the following is an outline of the Armstrong/Laird method, how it is becoming stream lined, and some proposed goals of the problem.

Claude Laird's computational procedure is summarized in the following diagram (figure 1). Here we are assuming that the energy spectrum of the proton fluxes can be validly described by the power law $\frac{dN}{dE} = A*E^{-\delta}$, where $\frac{dN}{dE}$ is the proton differential flux (number of protons per square cm sr sec MeV) and δ is the spectral exponent.

The differential flux for each energy, E, (which are 10 logarithmic midpoints of IMP8 proton channel energies, contained in the data file *DATUM.DAT*), and the spectral exponent, δ, for each of the 9 energy ranges (contained in the data file *ERANGE.DAT*) between the above 10 logarithmic spaced energies, are calculated using the program *NTOTAL1.FOR* which reads data from a daily average IMP8 tape and outputs the above calculated quantities to the tapes called *TOTAL TAPES.*

Reading from the *TOTAL TAPES*, the program *NTOTREC1.FOR*, using the subroutine *NPARTICLES.FOR*, performs the integration

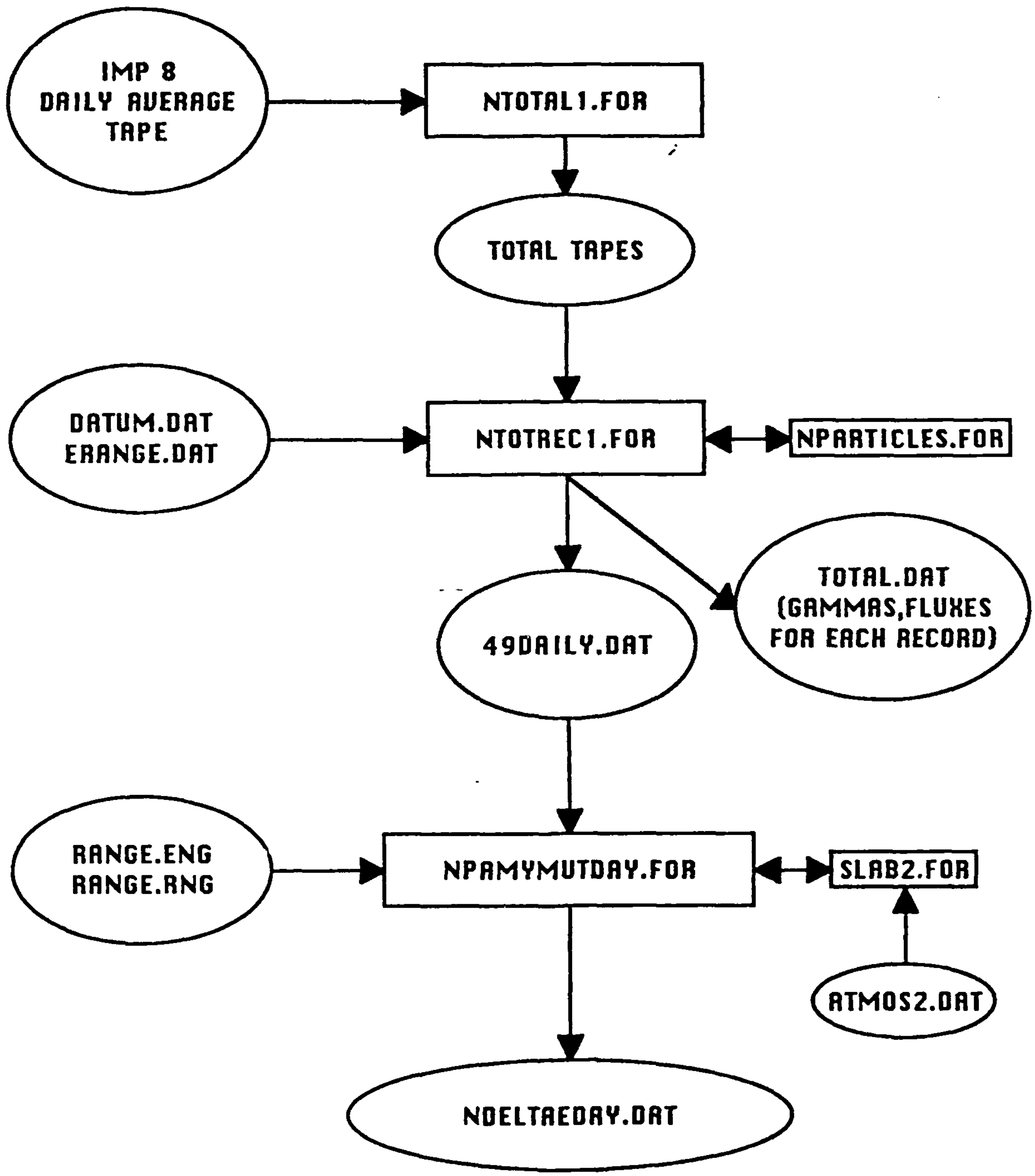
$$N_i = \frac{24\ \text{hrs}}{\text{day}} * \frac{3600\text{sec}}{\text{hr}} * \int_{E_i}^{E_{i+1}} \frac{dN}{dE} dE$$

, where E_i (i = 1,2,...,49) are logarithmic spaced energies ranging from 0.38 MeV to 289 MeV, giving 49 mono-energetic fluxes (number of protons per square cm sr sec) incident on the upper atmosphere with incident energies $E_i^0 = \sqrt{E_i * E_{i+1}}$, which are output in the data file *49DAILY.DAT*. *NTOTREC1.FOR* also outputs the data file *TOTAL.DAT*. which contains the differential flux and exponent data for the period considered.

The program *NPAMYMUTDAY.FOR*, which inputs the 49 mono-energetic fluxes contained in *49DAILY.DAT*, follows these fluxes through the atmosphere as energy deposited in each of the 5 km slabs is calculated using a table look up method using range and energy data contained the data files *RANGE.RNG* and *RANGE.ENG*. Subroutine *SLAB.FOR* returns to the program *NPAMYMUTDAY.FOR* the equivalent thicknesses of the slabs at sea level using monthly average atmospheric densities at the top and bottom of each atmospheric slab, contained in the data file *ATMOS2.DAT*. *NPAMYMUTDAY.FOR* outputs the total energy deposited per cubic cm in each slab and total number of ion pairs per cubic cm produced in each slab produced by the protons incident on the upper atmosphere for each day in the data file *NDELTAEDAY.DAT*.

A similar process is used to calculate the total energy deposited and the ion pairs produced in the 5 km slabs by the alpha particles. Summing the two gives the total number of ion pairs per cubic cm produced by both the alpha particles and protons in each slab each day.

Figure 1:



The above process has been stream lined to calculate, using input data from an IMP 8 daily average tape, the total number of ion pairs produced by both alpha particles and protons per cubic cm in each 5 km slab for each day, which is output in the data file *IONPAIRSnn.DAT*. In short, to summarize the stream lined process:

Input:

IMP 8 daily average tape.
Starting and end dates of the period desired.

Output:
IONPAIRSnn.DAT (nn equals the year minus 1900, e.g. for 1990 nn = 90)

The following diagram (figure 2) summarizes how the process has been stream lined

Program *NTOTAL1.FOR* has been converted into the subroutine *NTOT_SUB.FOR*, which is driven by the program *ION_PRS.FOR*. The user inputs into *ION_PRS.FOR* the starting and ending year and day of year of the dates *IONPAIRSnn.DAT* is wanted.

ION_PRS.FOR calls subroutine *NTOT_SUB.FOR* once each year of the desired dates. Subroutine *NTOT_SUB.FOR* reads data from the IMP8 tape, calls subroutines *NPART_SUB.FOR, NPARTAL_SUB.FOR, NPAM_SUB.FOR, NPAMAL_SUB.FOR,* and outputs data to *IONPAIRSnn.DAT* once each day of each year.

Subroutine *NPART_SUB.FOR* (subroutine *NPARTAL_SUB.FOR*) is the modified above subroutine *NPARTICLES.FOR*, which calculates the 49 mono-energetic proton fluxes (35 mono-energetic alpha particle fluxes).

Subroutine *NPAM_SUB.FOR* (subroutine *NPAMAL_SUB.FOR*),which is the modified program *NPAMYMUTDAY.FOR*, calculates the total energy deposited and number of ion pairs per cubic cm produced in each slab by the 49 (35) mono-energetic fluxes by using the subroutine *DEPOSIT.FOR* (*DEPOSITAL.FOR*).

Subroutine *DEPOSIT.FOR* (subroutine *DEPOSITAL.FOR*) integrates over pitch angle from 0 to pi/2 (assuming an isotropic distribution of pitch angle, and symmetric zenith angle) to calculate energy deposited by the table look up method using data files *RANGE.ENG* and *RANGE.RNG* (*AIR_ALPHAS.ENG* and *AIR_ALPHAS.RNG*) by each of the mono-energetic fluxes.

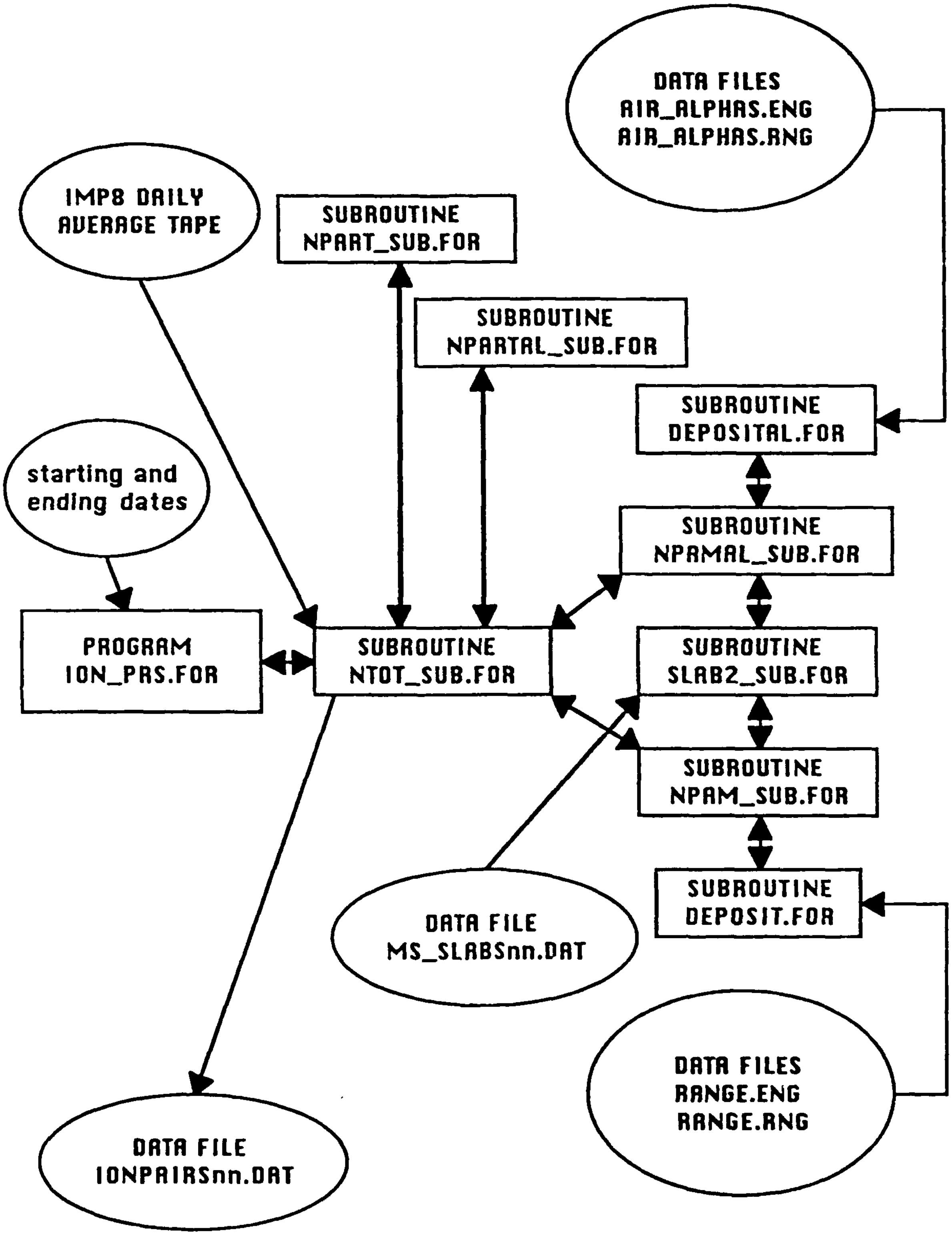
Subroutine *SLAB2_SUB.FOR*, modified version of the above subroutine *SLAB2.FOR*, returns equivalent sea level thickness to the subroutines *NPAM_SUB.FOR* and *NPAMAL_SUB.FOR* for each date using monthly average densities at the top and bottom of each slab, which is contained in the data file *MS_SLABSnn.DAT* (nn = year - 1900).

The data files *MS_SLABSnn.DAT* were created using *MSIS* (Mass Spectrometer and Incoherent Scatter model) and *MSISE* (the extended MSIS model) atmospheric models.

The *MSIS* model has a lower limit of 80 km, the *MSISE* model is for altitudes greater than 0 km (the latter is the extended version of the former, but is not recommended over the former for altitudes greater than 85 km).

These models, which were obtained from NSSDC (NASA's National Space Science Center), require the parameters day of year, universal time, altitude, geodetic latitude and longitude, local apparent solar time, three month average of 10.7cm solar radio flux, daily 10.7cm solar radio flux for previous day, and daily AP magnetic activity index. The daily 10.7cm solar radio flux and the daily AP magnetic activity index were obtained from *Solar Geophysical Data*.

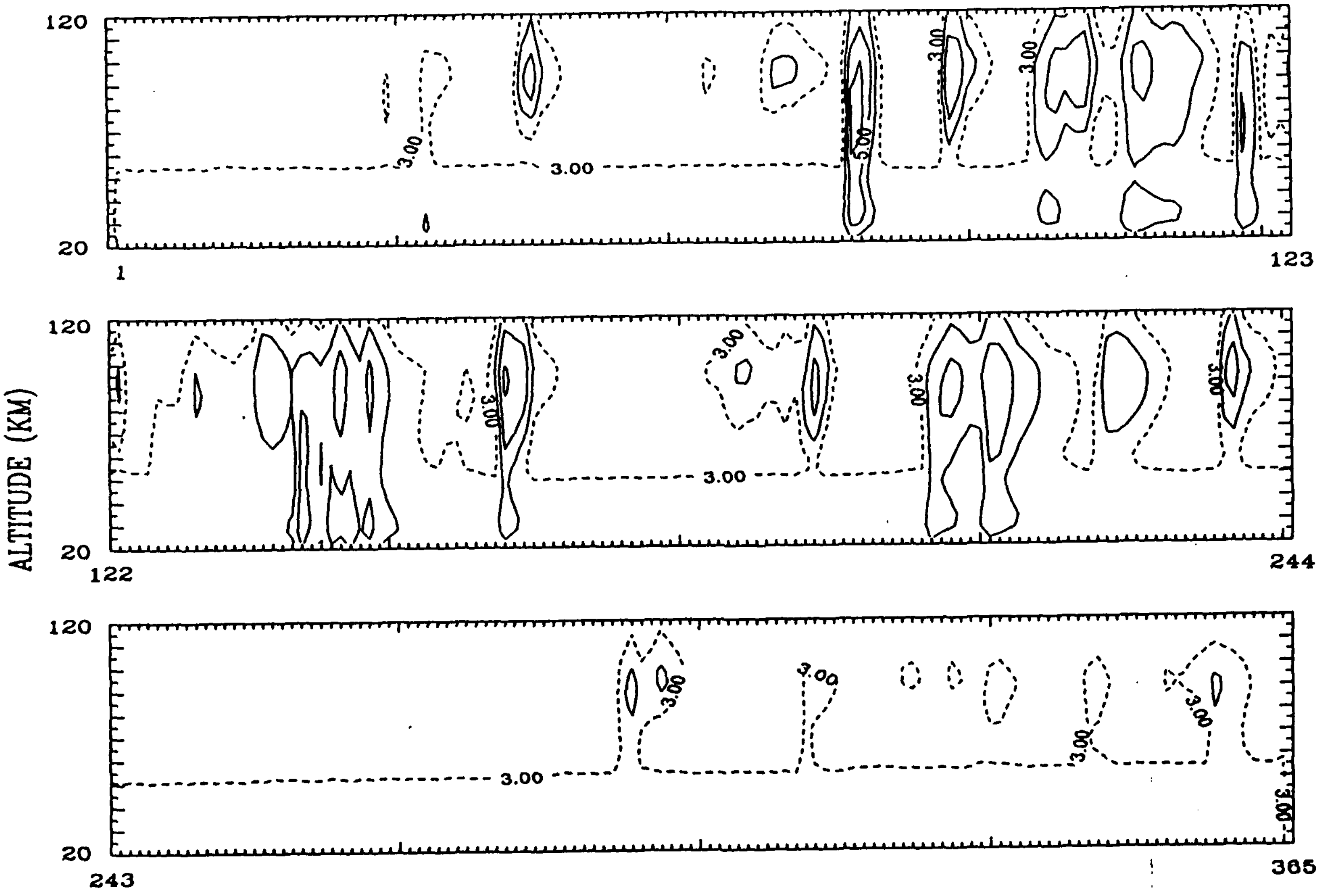
Figure 2:



The results of running the process using the atmospheric model which Claude La... has used has been compared to the results of using the MSIS and MSISE atmospheric models. The largest discrepancies appear to occur during periods of relatively large sola...

activity. To illustrate this, figures 3 and 4 are contour plots of the log of number of ion pairs per cubic cm per hr by protons and alpha particles from the results of running the process using Claude Laird's atmospheric model for years 1990 and 1991, while figures 5 and 6 are the result of using the MSIS models. Figures 7 and 8 are contour plots of the log of absolute value of the difference in the results of using the two models for 1990 and 1991. As you can see, the larger discrepancy occurs during the periods of when solar events have occurred. This is probably a result of the MSIS models use the daily 10.7cm solar radio flux and the daily AP magnetic activity index, which are high during these periods.

A suggested goal of the calculation is to link the input ion pair distribution with vertical transport of the ions and their life times. That is, after calculating the total number of ion pairs per cubic cm produced in each slab for a given day, we need to add to the total the number of ion pairs per cubic cm which do not recombine, and are transported into each slab from slabs above and below from previous days. So that we are calculating the total number ion pairs per cubic cm in each slab each day, not just the ionization produced each day.

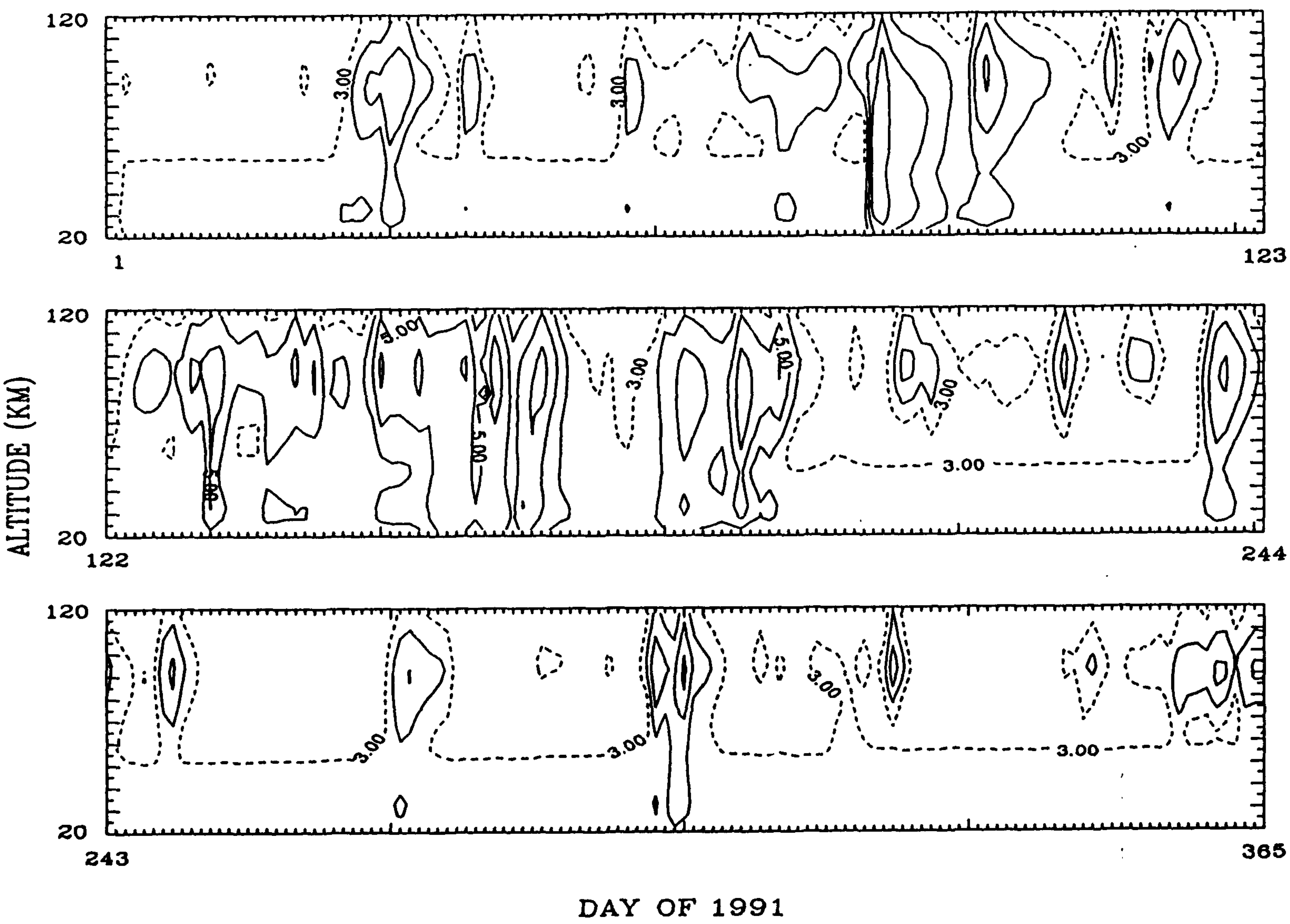


DAY OF 1990

LOG ION PAIRS/CUBIC CM–HR

(PROTONS + ALPHAS)

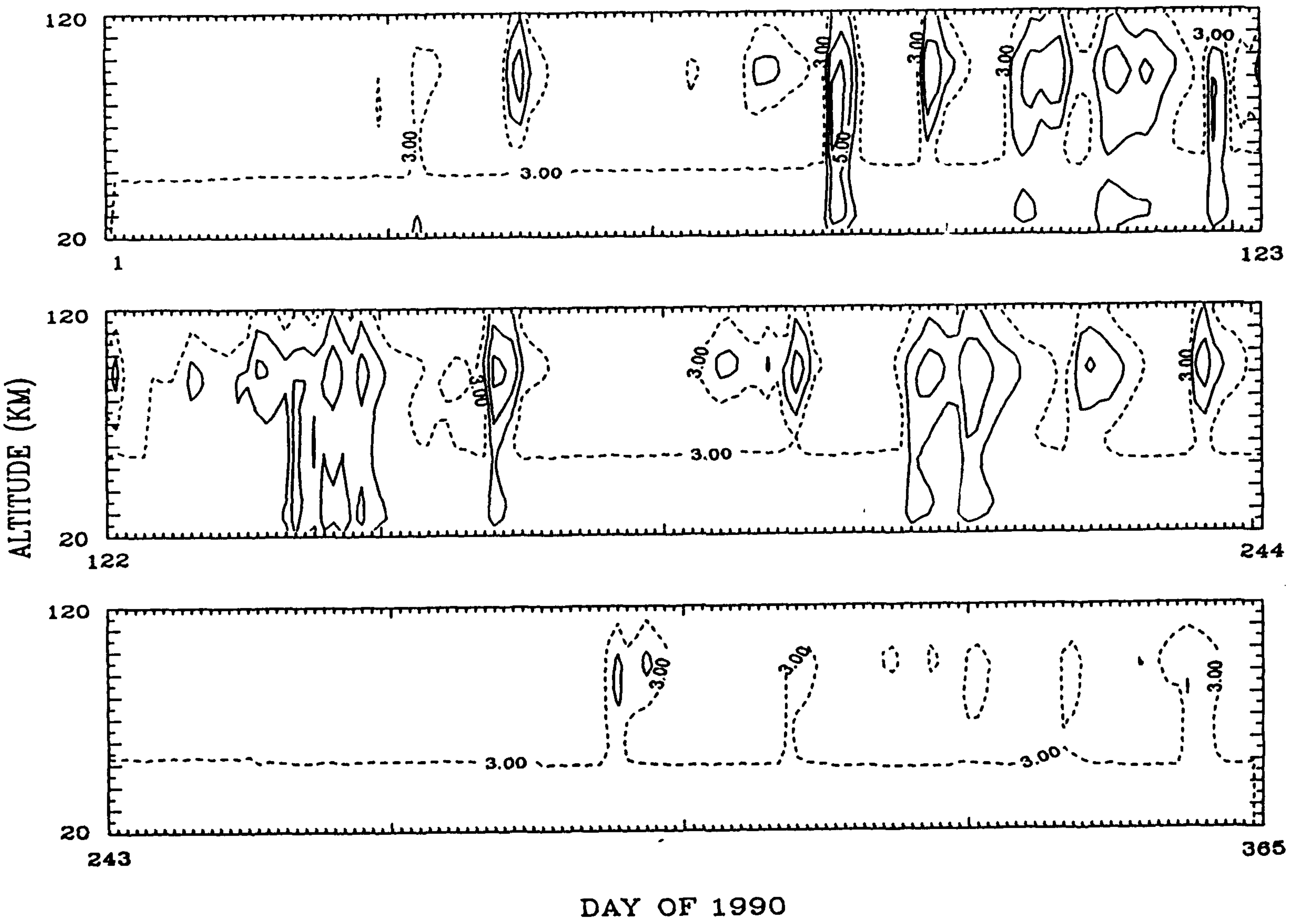
FIGURE 3



LOG ION PAIRS/CUBIC CM−HR

(PROTONS + ALPHAS)

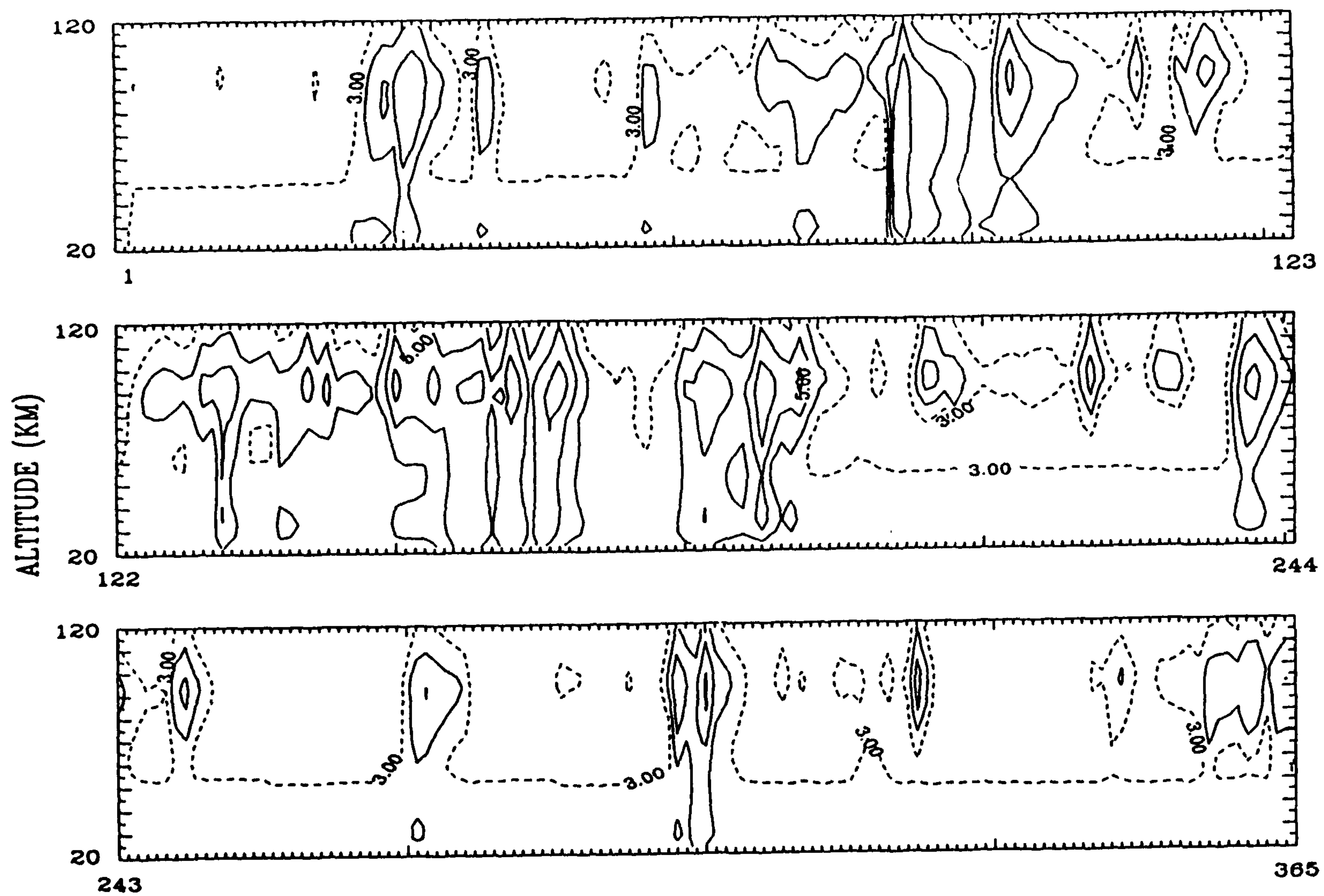
FIGURE 4



LOG ION PAIRS/CUBIC CM–HR

(PROTONS + ALPHAS)

FIGURE 5

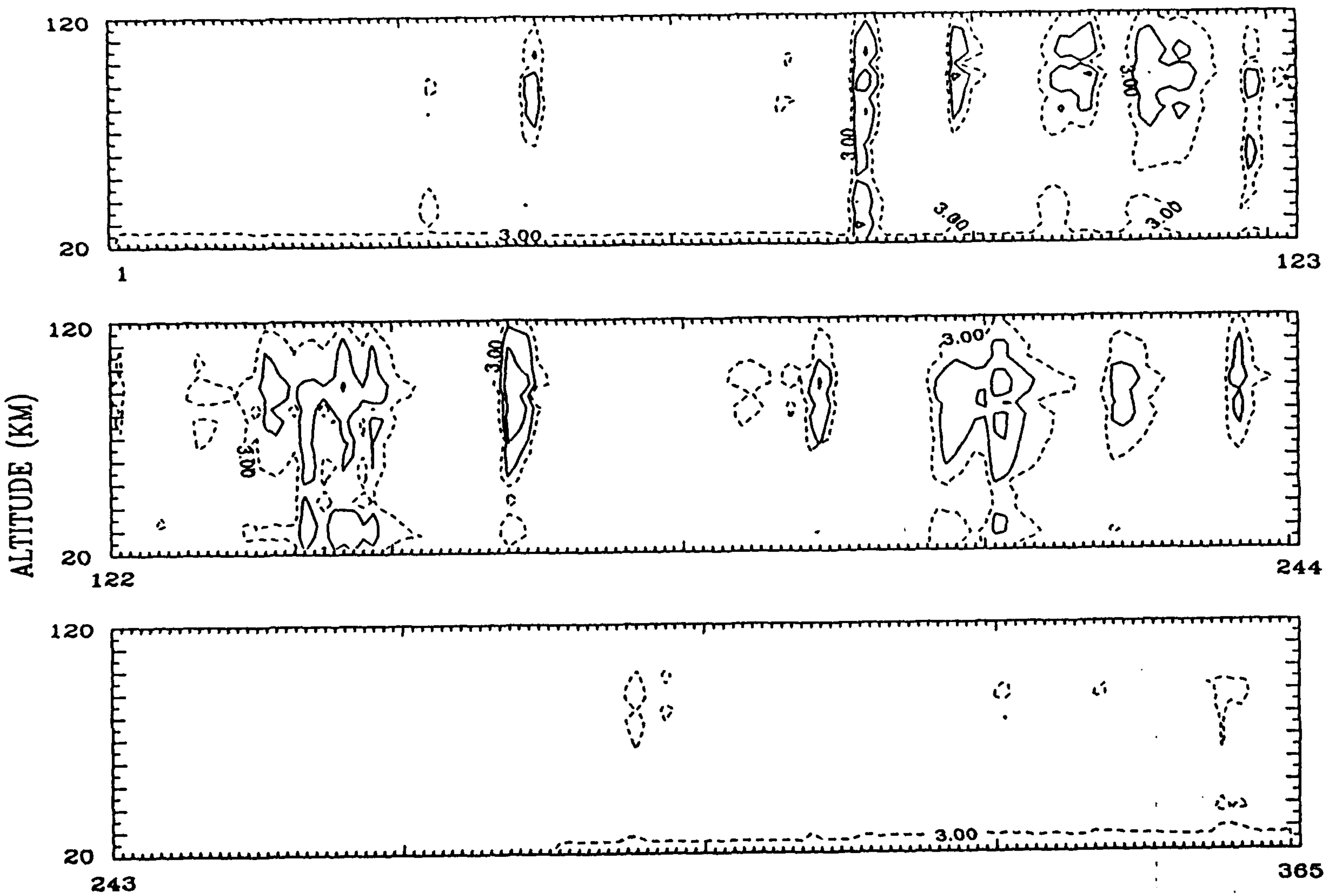


DAY OF 1991

LOG ION PAIRS/CUBIC CM–HR

(PROTONS + ALPHAS)

FIGURE 6

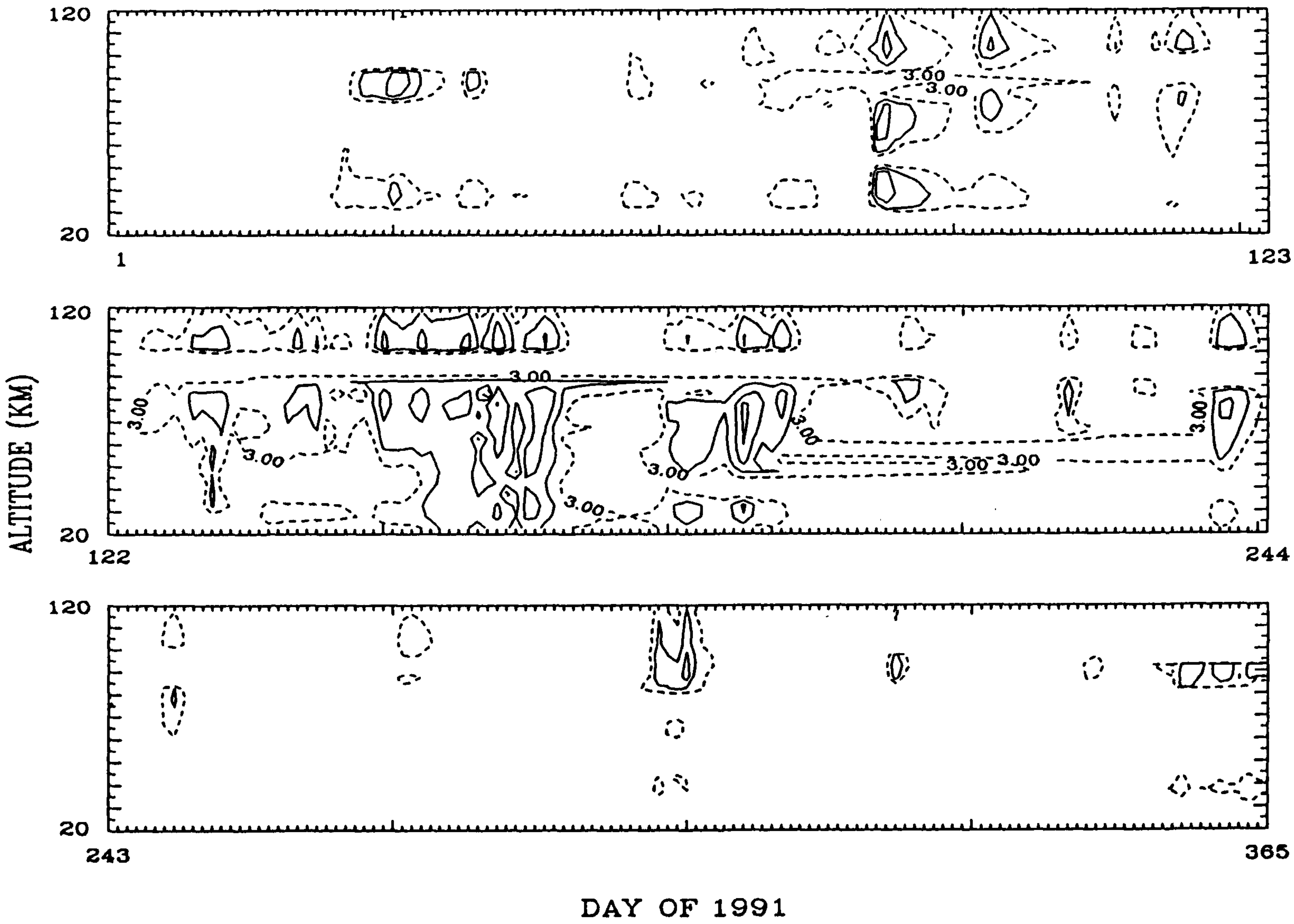


DAY OF 1990

LOG ABS(DIFF ION PAIRS/CUBIC CM−HR)

(PROTONS + ALPHAS)

FIGURE 7



LOG ABS(DIFF ION PAIRS/CUBIC CM−HR)

(PROTONS + ALPHAS)

FIGURE 8

August 6, 1992

Regarding the calculation of ion pairs produced by energetic protons incident on the upper atmosphere using IMP8 data which has been done by Claud Laird and Charlie Jackman, daily average IMP8 data for day 293 of 1989 has been used. Integration of ion pairs per cubic cm over the altitude shows that Jackman's method tends to give more ionization than Laird's method, by about a factor of two. (See figure 1. Here the circles represent Laird's results, triangles represent Jackman's results.) To find the discrepancy between the two methods the following comparisons were done. Modifications were done to the Laird method to attempt to obtain results that match Jackman's.

Comparison of the two methods:

* Both assume that the number of ion pairs produced equals the energy deposited by the protons in the atmosphere divided by 35 eV.

* Laird uses the power law energy spectrum $\frac{dN}{dE} = A*E^{-\delta}$, where $\frac{dN}{dE}$ is the differential flux (no. of particles $*cm^{-2}*sr^{-1}*sec.^{-1}*$ MeV^{-1}), A is the flux constant, δ is the spectral exponent. A and δ are determined over nine energy ranges to fit the IMP8 data. This gives a piece wise continuous spectrum. (See figure 2.)

* Jackman uses an exponential energy spectrum given by $\frac{dN}{dE} = F*\exp(\frac{E}{E_0})$, where F and E_0 are determined over only four energy ranges to fit the the IMP8 data. This gives relatively large discontinuities in the energy spectrum. (See figure 3.)

* Laird's energy spectrum ranges from 0.38 MeV to 289 MeV.

* Jackman's energy spectrum ranges from 0.29 MeV to 440 MeV.

* Laird's method:

Integration of the energy spectrum gives

$$N_i = \frac{24\ hrs}{day} * \frac{3600 sec}{hr} * \int_{E_i}^{E_{i+1}} \frac{dN}{dE} dE$$

= total no. of particles $cm^{-2}\ sr^{-1}$ incident on the upper atmosphere for the day,

where E_i (i = 1,2,...,50) are logarithmically spaced energies ranging from 0.38 MeV to 289 MeV. This gives 49 mono-energetic fluxes with incident energy $E_i^0 = \sqrt{E_i * E_{i+1}}$.

These fluxes are followed vertically through the atmosphere, which is divided into 5 km slabs, as energy deposited in each slab is calculated, using a table look up method. Hence calculating energy deposited $cm^{-2}\ sr^{-1}$. Then Laird multiplies by

$\left(\frac{1}{35\times10^{-6}\mathrm{MeV}}\ \frac{1}{5\times10^{5}\mathrm{cm}}\ \frac{2\pi}{3}s\right)$ to get the units of no. of ion pairs cm^{-3}.

* Jackman's method:

Jackman assumes an isotropic distribution of pitch angle and azimuthal symmetry. Jackman calculates no. of ion pairs$*cm^{-3}*sec.^{-1}$ using the expression

$$q(z) = \rho(z)\int_B\int_\Omega \frac{dE}{dx}\frac{1}{w}\frac{dN}{dE}\,dE\,d\Omega\ ,$$

where $\frac{dN}{dE}$ is the differential flux (no.$*cm^{-2}*sr^{-1}*sec.^{-1}*MeV^{-1}$), w = 35 eV per ion pair, $\rho(z)$ is the atmospheric density at the altitude z, $\frac{dE}{dx}$ is the energy deposited per gm.

Let E_D = dE be the energy deposited by a particle of energy E with a pitch angle α in the segment z_D, z_D = width of the atmospheric layer in gm$*cm^{-2}$ centered on the altitude z.

If $\frac{dN}{dE}(E_0,\alpha,z)$ = flux of particles with incident energy E_0 at a pitch angle α at the altitude z is known, then $q_{i,j}(\Delta,z)$ = ionization rate by a flux of particles in the energy interval $E_0 - \frac{\Delta E}{2}$ to $E_0 + \frac{\Delta E}{2}$, and in the pitch angle interval $\alpha - \frac{\Delta\alpha}{2}$ to $\alpha + \frac{\Delta\alpha}{2}$ over the atmospheric distance z_D centered on the altitude z can be calculated with the expression

$$q_{i,j}(\Delta,z) = 2\pi\int_{E_0-\frac{\Delta E_0}{2}}^{E_0+\frac{\Delta E_0}{2}}\int_{\alpha-\frac{\Delta\alpha}{2}}^{\alpha+\frac{\Delta\alpha}{2}} E_D\,\frac{\frac{dN}{dE}(E_0,\alpha,z)}{w\,z_D\sec\alpha}\,\sin\alpha\,d\alpha\,dE\ .$$

Assuming E_D and $\frac{dN}{dE}(E_0,\alpha,z)$ change slowly enough within the pitch angle interval we can write

$$q_{i,j}(\Delta,z) = \frac{2\pi}{W\,z_D}\int_{E_0-\frac{\Delta E}{2}}^{E_0+\frac{\Delta E}{2}} \frac{dN}{dE}(E_0,\alpha,z)\,E_D\,dE \int_{\alpha-\frac{\alpha}{2}}^{\alpha+\frac{\alpha}{2}} \cos\alpha \sin\alpha \, d\alpha$$

$$= \frac{\pi}{W\,z_D}\left[\sin^2(\alpha+\frac{\Delta\alpha}{2}) - \sin^2(\alpha-\frac{\Delta\alpha}{2})\right] \int_{E_0-\frac{\Delta E}{2}}^{E_0+\frac{\Delta E}{2}} \frac{dN}{dE}(E_0,\alpha,z)\,E_D\,dE .$$

To calculate the energy deposited Jackman uses the expression for the range as $R(E) = A*E^B$, thus $E_D = E - (-\frac{z_D * \sec\alpha}{A} + E^B)^{\frac{1}{B}}$.

Hence, the ionization rate at the altitude z is

$$q(z) = \rho(z) \sum_{i,j} q_{i,j}(\Delta,z)$$

$$= \text{no. of ion pairs cm}^{-3}\ \text{sec.}^{-1}.$$

Modifications to the Laird method:

Assume an isotropic distribution of pitch angle between 0 and $\frac{\pi}{2}$ and azimuthal symmetry. Let α_k be 50 evenly spaced angles between 0 and $\frac{\pi}{2}$, the fluxes with pitch angle between α_k and α_{k+1} have the pitch angle α_k^0 such that $\cos\alpha_k^0 = \sqrt{\cos\alpha_k * \cos\alpha_{k+1}}$.

Let $q_{i,j,k}$ = the no. of ion pairs*cm^{-3} produced by the flux with incident energy E_i^0 in the jth slab centered at altitude z_j with pitch angle α_k^0. So,

$$q_{i,j,k} = \frac{1}{35\text{x}10^{-6}\text{MeV}} \int_{\Delta\Omega} N_i \frac{E_{D,i,j,k}}{\Delta X_{j,k}} d\Omega ,$$

where $E_{D,i,j,k}$ is the energy deposited by a proton with incident energy E_i^0, pitch angle α_k^0, in the jth slab. $\Delta X_{j,k}$ is the effective thickness of the jth slab, i.e. $\Delta X_{j,k} = \Delta Z_j * \sec\alpha_k^0$. ΔZ_j is the thickness of the slab (5km). N_i (for i = 1,2,...49) is the mono-energetic flux with incident energy E_i^0. And $\Delta\Omega$ is the solid angle between α_k and α_{k+1} as Φ varies from 0 to 2π.

Assuming N_i, $E_{D,i,j,k}$, and $\Delta X_{j,k}$ do not change significantly as pitch angle varies between α_k and α_{k+1}, we can write

$$q_{i,j,k} = \frac{1}{35x10^{-6}MeV} N_i \frac{E_{D,i,j,k}}{\Delta Z_j} (\cos \alpha_k^0) \Delta\Omega_k ,$$

where

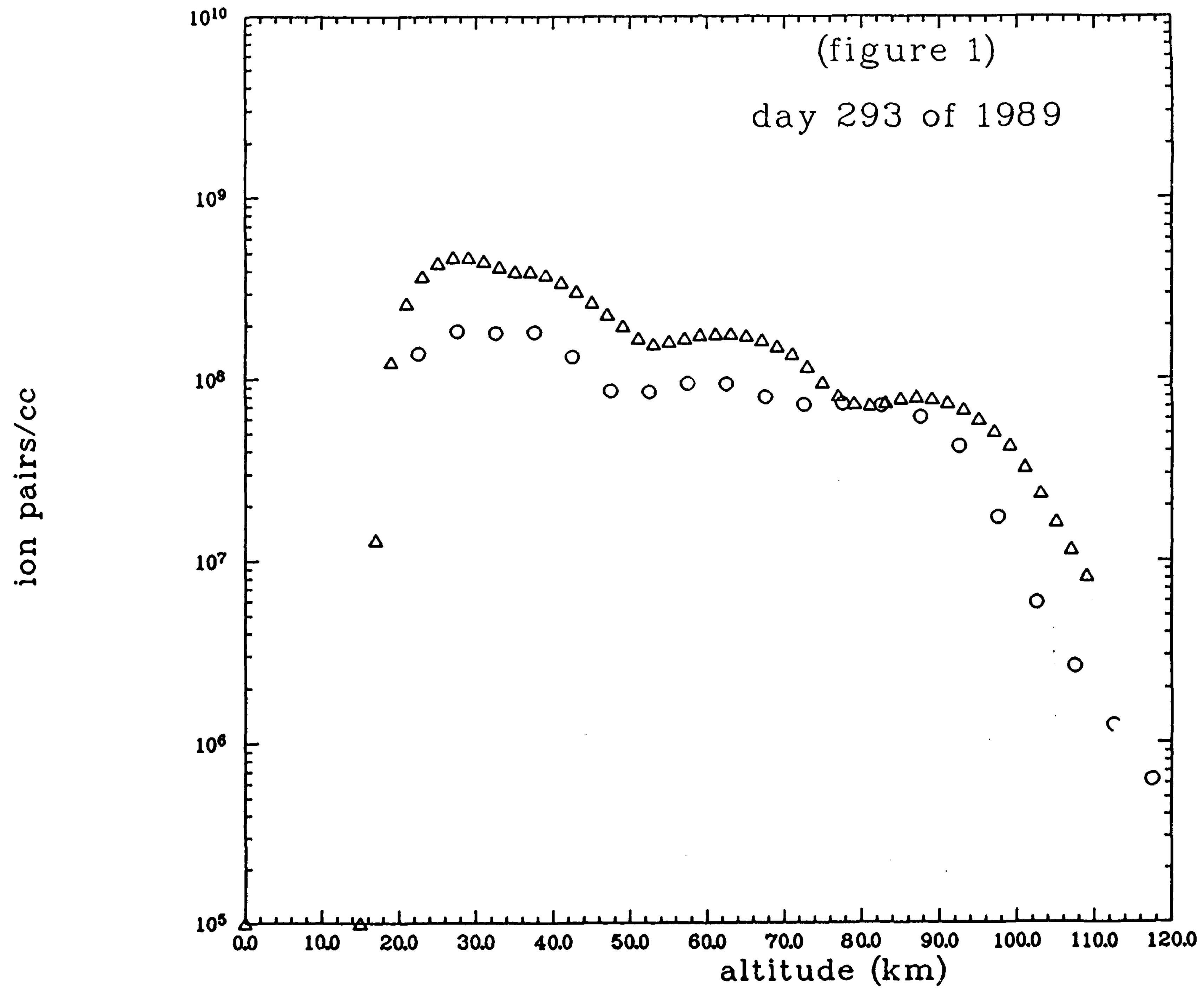
$$\Delta\Omega_k = \int_0^{2\pi} d\Phi \int_{\alpha_k}^{\alpha_{k+1}} \sin \vartheta d\vartheta = 2\pi(\cos\alpha_{k+1} - \cos \alpha_k) .$$

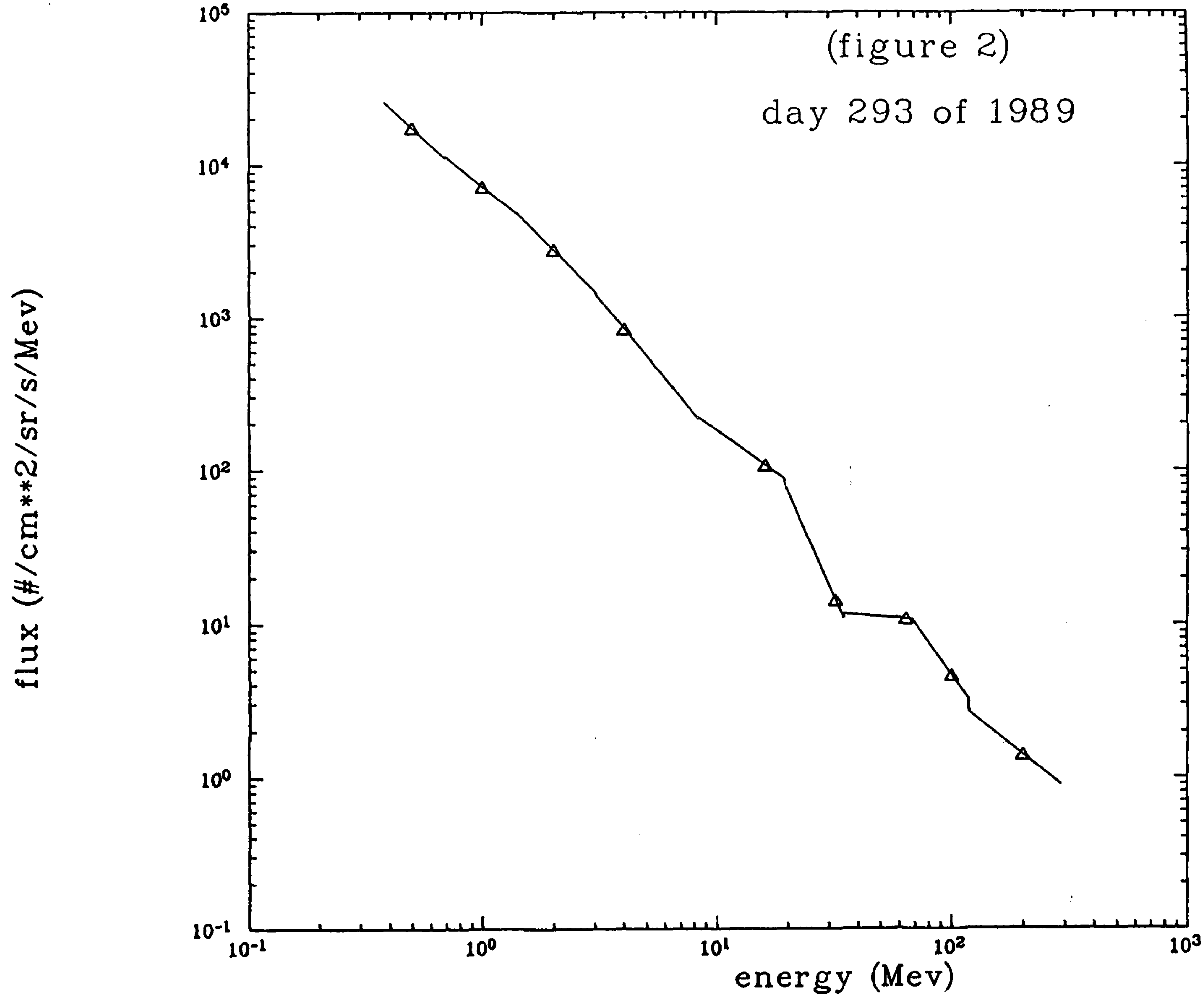
Summing over incident energies and pitch angles we can calculated the total no. of ion pairs cm^{-3} produced the the jth slab, Q_j, i.e.

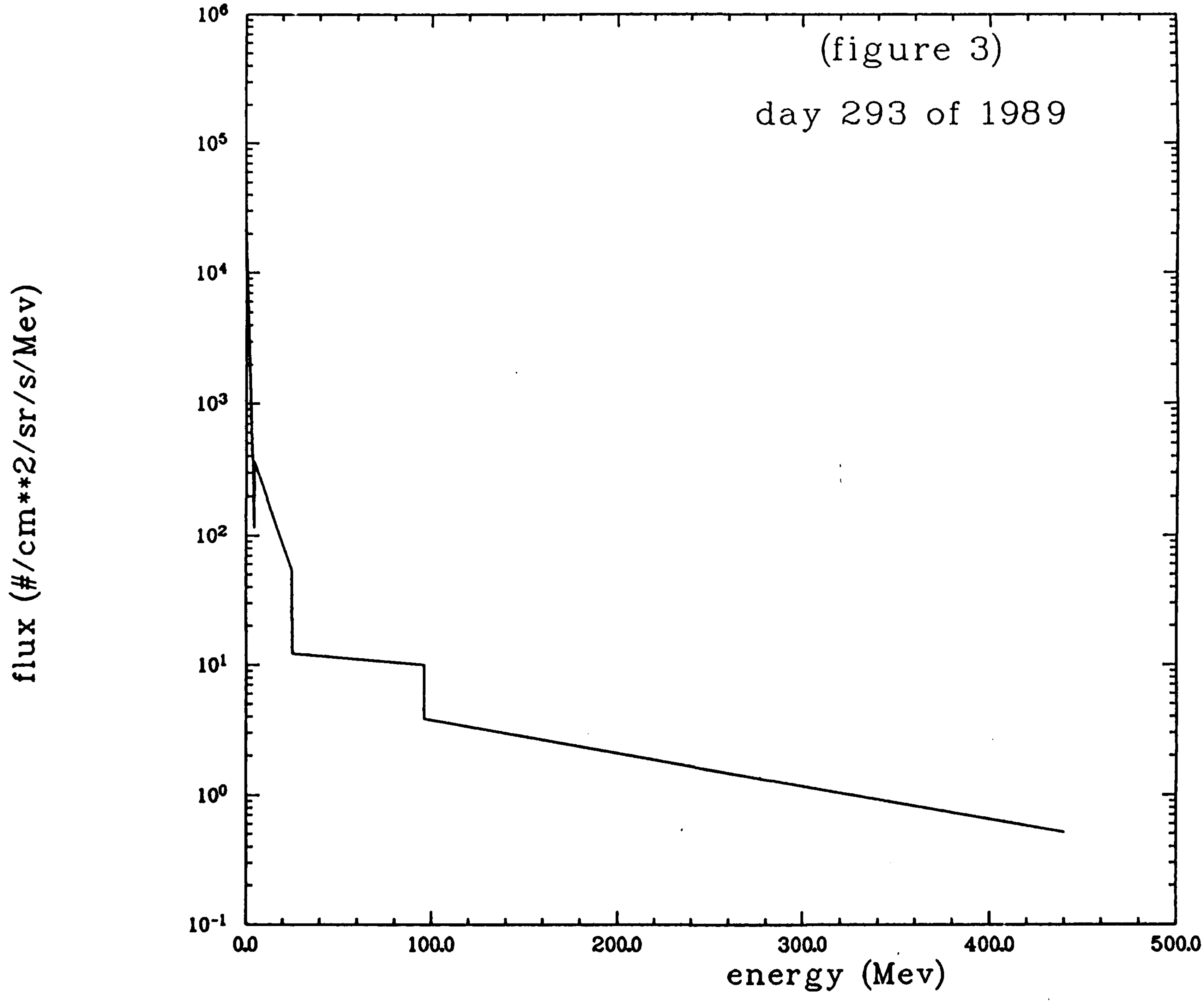
$$Q_j = \sum_{i,k} q_{i,j,k} .$$

Integrating the ion pairs cm^{-3} produced over altitude, where Laird's power law spectrum was used to calculate the 49 mono-energetic fluxes, gives gives a higher ionization for the modified Laird method by about a factor of 1.5 compared to the results of the unmodified Laird method for day 293 of 1989. (See figure 4. Here the circles represent the results of the unmodified Laird method, the triangles represent Jackman's results, while the squares represent the results of the modified Laird method.)

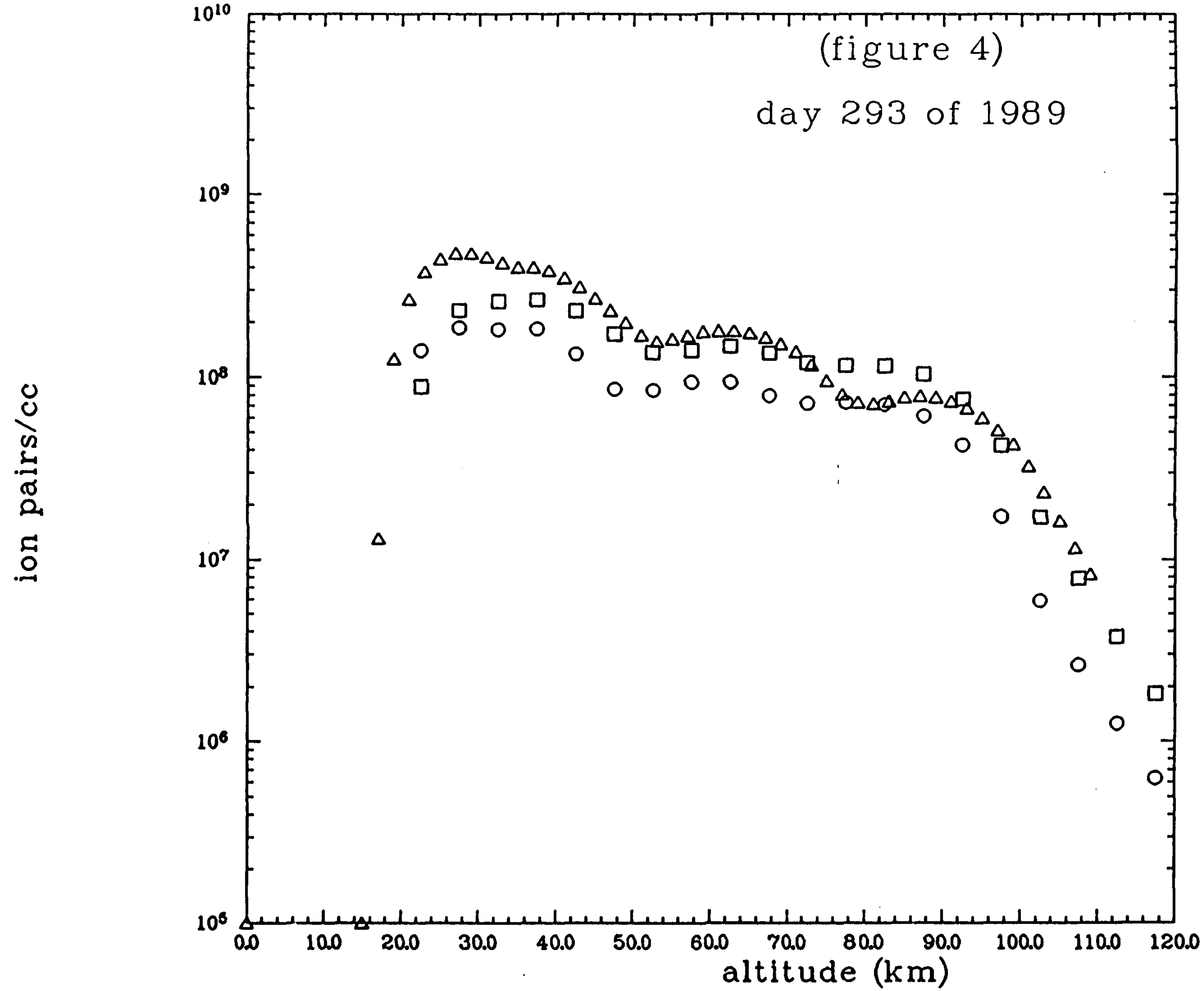
Using Jackman's exponential spectrum to calculate the 49 mono-energetic fluxes for the modified Laird method gives a result which very closely resembles Jackmam's. (See figure 5. The circles, triangles, and squares represent the same as in figure 4.)

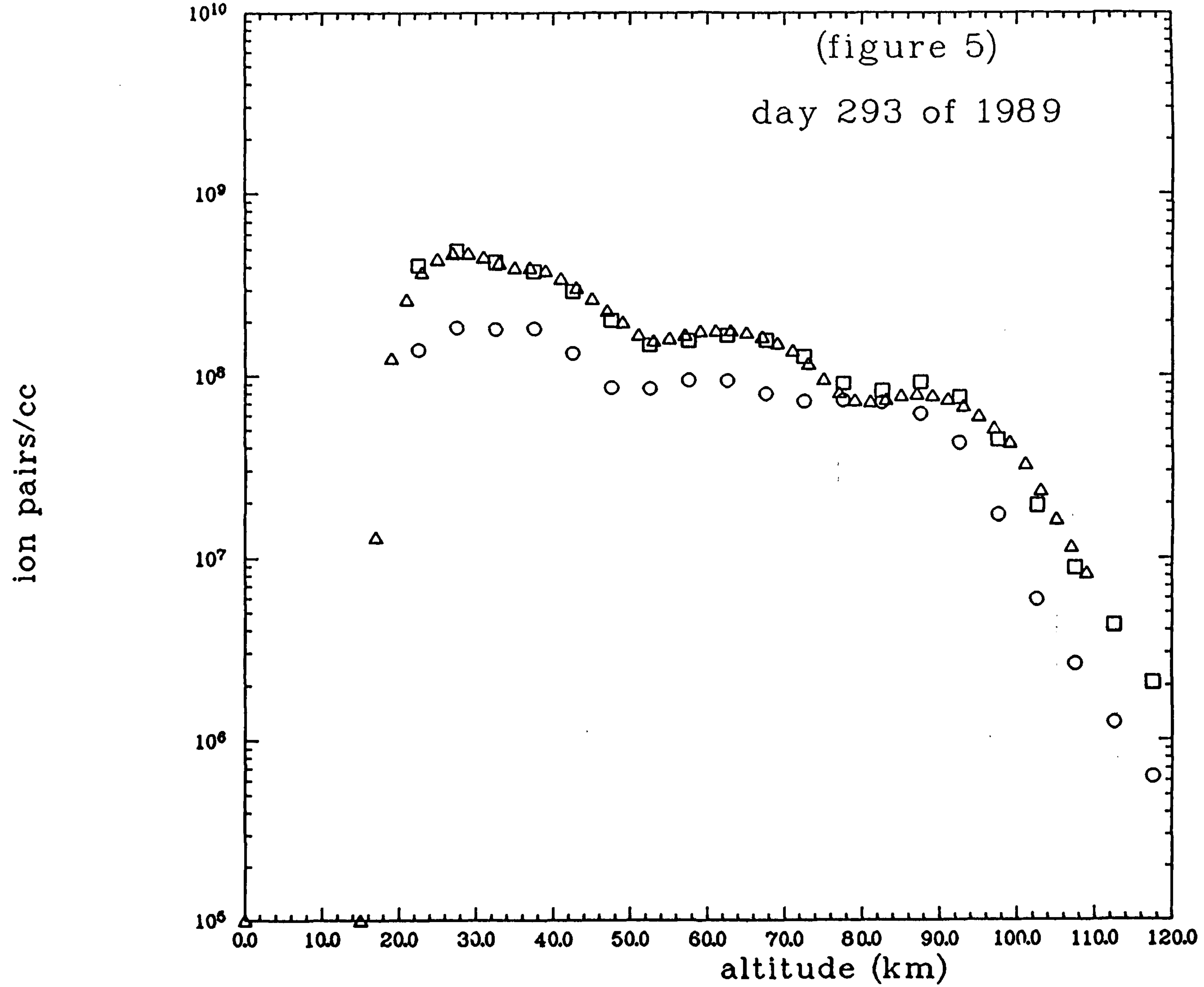

(figure 1)
day 293 of 1989
ion pairs/cc
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0
120.0
altitude (km)


(figure 2)
day 293 of 1989
flux (#/cm**2/sr/s/Mev)
energy (Mev)
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
10^-1
10^0
10^1
10^2
10^3



(figure 3)
day 293 of 1989
flux (#/cm**2/sr/s/Mev)
energy (Mev)
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
0.0
100.0
200.0
300.0
400.0
500.0


(figure 4)
day 293 of 1989
ion pairs/cc
altitude (km)
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0
120.0


(figure 5)
day 293 of 1989
ion pairs/cc
altitude (km)
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0
120.0

June 8, 1993

MEMO

FROM: Francis Vitt

During solar proton events large number of energetic protons, which are detected by IMP8, are released by the sun. By using an energy deposition program we are able to calculate ion pair production rates versus altitude from IMP8 daily averaged proton count rates. The energy deposited is calculated as the protons are allowed to propagate down through the extended MSIS model atmosphere (ref. Hedin A.E., *Extension of the MSIS Thermosphere Model into the Middle and Lower Atmosphere,* J.G.R., 96, A2, 1159, 1991).

These ion pair production rate profiles have been compared to the ion pair production rates calculated by Nicolet in 1975 due to galactic cosmic rays, i.e. protons from outside the solar system, (ref. Nicolet, M., *On the production of Nitric Oxides by Cosmic Rays in the Mesosphere and Stratosphere,* Planet Space Sci., 23, 637, 1975). It was found that the ion pair production rates calculated using the IMP8 data fell short of the ion pair production rates calculated by Nicolet by about an order of magnitude in the lower altitudes. This may be caused by the fact that IMP8 can not detect protons of energies greater than 440 MeV and the energies of the galactic ray protons are much greater than this. This is remedied by adjusting the IMP8 data by subtracting the back ground from the count rates, using the adjusted data to the calculate ion pair production rates with the energy deposition program, then adding to these ion pair production rates the rates calculated by Nicolet, i.e. the ion pair production rates due to the galactic cosmic rays are added to the adjusted production rates due to the solar proton events.

With an estimated ratio, obtained from the literature, of the ion pairs produced to odd nitrogen species produced gives a production rate of odd nitrogen. Using the production rates due to solar proton events as odd nitrogen production rate coupled with chemical production rates and loss rates, coupled with transport processes will give a time dependent model of the odd nitrogen profiles. Currently, a one dimensional diffusion problem with appropriate source and loss terms in the continuity equation is being solved.